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The Effects of a Professional Development Program on Elementary and Middle School Teachers' Understanding and Acceptance of Macroevolution and How They Teach It

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The Effects of a Professional Development Program on Elementary and Middle School Teachers' Understanding and Acceptance of Macroevolution and How They Teach It

by

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Dedication

This dissertation is dedicated to my boys. May nothing stop you from reaching your goals.

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The Effects of a Professional Development Program on Elementary and Middle School Teachers' Understanding and Acceptance of Macroevolution and How They Teach It

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Despite science education reform efforts stressing the importance of understanding evolution, many students receive little to no exposure to the most important unifying concept in biology. Since evolution is basic to the study of biology, its study should begin with the introduction of the life sciences to students in elementary school. However, many teachers lack sufficient evolutionary content knowledge, have limited acceptance of evolution, and have little confidence to effectively teach it. Better teacher preparation is needed to meet the challenges of ensuring students develop conceptual understanding of evolution.

While research shows the general public typically accepts microevolution while rejecting macroevolution, few studies have focused on peoples' understanding of macroevolution. Additionally, little research exists examining the effects of an intervention on elementary and middle school teachers' acceptance, understanding, and teaching of macroevolution. Using a conceptual framework based on the Cognitive Reconstruction of Knowledge Model, this study reports the effects of a sustained professional development program on 4th through 8th grade teachers' acceptance of evolution; understanding of macroevolution; and approach to teaching evolution in

schools, awareness of challenges to teaching evolution, and pedagogical content knowledge about teaching macroevolution. This study also explores the relationship between teachers' understanding of macroevolution and acceptance of evolution. Various data sources, including the Measurement of the Understanding of Macroevolution (Nadelson & Southerland, 2010), the Measure of the Acceptance of the Theory of Evolution (Rutledge & Warden, 1999), teacher interviews, and teacher workshop reflections, were used to answer the research questions.

Results from the study revealed that after attending the professional development series, teachers' understanding of macroevolution and acceptance of evolution significantly increased. Acceptance of evolution was positively correlated to understanding of macroevolution. Teachers' prior understanding of macroevolution was a significant positive predictor of their subsequent acceptance of evolution. Teachers' prior acceptance of evolution was a significant predictor of their understanding of macroevolution, but only after teachers participated in at least half of the sustained professional development. Finally, teachers demonstrated having increased macroevolutionary pedagogical content knowledge. This effect was strong in those teachers who were initially low acceptors of evolution. The significance of these findings is discussed.

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Chapter One: Introduction

The rich diversity of life on Earth is the result of 3.7 billion years of evolution. From unraveling the mysteries of the origin of life, to discovering new but extinct species in the fossil record and recognizing the effects of environmental change on species survival, biological evolution is central to understanding our world. Science education reform efforts have acknowledged the importance of evolution by emphasizing the need for students to develop a rich understanding of evolutionary processes in order to integrate knowledge of the natural world. Science and educational organizations formally recognize evolutionary theory as the ultimate framework for biology and call for evolution instruction to be integrated into the science curriculum (AAAS, 2006; NABT, 2008; NRC, 1996; NSTA, 2003).

Despite the efforts of science education reformers to stress the importance of understanding evolution, many students receive little to no exposure to the most important unifying concept in biology (National Academy of Sciences, 1998). Teachers are vital to ensuring that student understanding of evolutionary concepts aligns with scientific understanding. However, many teachers, especially those who teach in elementary and middle schools, lack sufficient content knowledge and confidence to effectively teach their students evolutionary biology. Teachers must be better prepared to meet the challenge of ensuring that students develop conceptual understanding of the unifying framework for biology – evolution.

Statement of the Problem

Students enter classrooms, not as empty vessels needing to be filled, but as young minds with their own set of beliefs and assumptions about the world; many of these beliefs and assumptions are perceived to be directly challenged when taught evolution (Dagher & BouJaoude, 1997). Dagher and BouJaoude (1997, p. 431) explain, "The historical record shows that teaching evolution ushered into schools a worldview that ran contrary to some prevalent worldviews." For example, a 2012 Gallup survey noted that polls conducted over the past 29 years show a plurality of Americans agree with the statement: "God created human beings pretty much in the present form at one time within the last 10,000 years or so" (Newport, 2012, para. 1). Clearly, a large portion of the American public does not understand and/or accept evolutionary theory.

Although there is no serious dispute among scientists about the scientific accuracy of biological evolution, a significant proportion of the American public rejects evolution on religious and political grounds (Newport, 2012; Scott & Branch, 2003). There are movements throughout the nation to ensure that evolution, as well as alternatives to evolution, such as creationism and/or intelligent design, are taught (Couloumbis & Worden, 2013; Haley, 2013). Thus, many teachers avoid teaching evolutionary concepts because they do not believe in the theory of evolution or they want to avoid inciting conflicts with students' and parents' religious beliefs (Ashgar, Wiles, & Alters, 2007).

Even when teachers do teach their students evolutionary theory, their understanding is rarely consistent with scientific understanding and significant numbers of people retain misconceptions (Bishop & Anderson, 1999; Brumby, 1984; Nadelson, 2009; Nehm & Schonfeld, 2007). This problem is consistently reported in the literature pertaining to kindergarten through college students (Bishop & Anderson, 1990), medical students (Brumby, 1984), teachers (Nadelson & Nadelson, 2010), and the general public (Evans et al., 2006). To address this, a variety of pedagogical and curricular strategies focusing on student understanding and acceptance of evolution have been developed and implemented (Nehm & Schonfeld, 2007). The effectiveness of these strategies varies widely.

Barriers to peoples' understanding of evolution arise for many reasons, including a student's innate perceptions of the world which are counter to scientific conceptions, deeply held religious beliefs, misunderstanding the nature of science, confusing terminology, and a lack of understanding of specific scientific concepts (Chuang, 2003; Griffith & Brem, 2004; Mead & Scott, 2010b; Sinatra et al., 2008).

Multiple variables combine to influence learning evolution; thus learning is seldom a straightforward, rational, or linear process (Sinatra et al., 2008). Teachers must understand the multiple barriers influencing student understanding of evolution, and know how to address the barriers to develop conceptual understanding. Ensuring that people understand evolution is not simply a matter of adding to their existing knowledge; understanding evolution requires people to revise their previous models of the world to create an entirely new understanding. This type of learning, referred to as conceptual change, is difficult to achieve (Sinatra et al., 2008).

Science teachers are the critical component bridging scientists' understanding of evolution and public understanding of it (Nehm & Schonfeld, 2007). "Excellent teachers inspire young people to develop analytical and problem solving skills, the ability to interpret information and communicate what they learn, and ultimately master conceptual understanding. Simply stated, teachers are the key to improving student performance" (National Research Council, 2007, p. 113).

Teachers are on the forefront of assuring that the overarching goal of the National Science Education Standards (NSES), to ensure that the United States has a scientifically literate populace in which individuals are able to identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed, is met (National Research Council, 1996). Blank and Anderson (1997) explain:

> The choice of content and activities that teachers make, their interactions with students, the habits of mind that teachers demonstrate and nurture among their students, and attitudes (conveyed wittingly and unwittingly) all affect the understanding, reasoning, and attitudes that students develop. (p. 28).

Given that teachers have the opportunity to be potent agents of change within the classroom, their understanding and acceptance of science content, such as the theory of evolution, may govern whether the goals of the National Science Education Standards are met (Blank & Anderson, 1997).

The key to achieving a scientifically literate populace is through science education. According to the NSES, students should be able to (National Research Council, 1996):

> experience the richness and excitement of knowing about and understanding the natural world; use appropriate scientific processes and principles in making personal decisions; engage intelligently in public discourse and debate about matters of scientific and technological concern; and increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers. (p. 13)

Teachers tend to hold positivist and transmissionist views of teaching, which are in direct conflict with the reform-based goals and methodologies that are advocated by the NSES (Borasi & Fonzi, 2002). In most instances, actual science instruction is not aligned with the NSES goals, causing students to be under-prepared for future careers in science, as well as to fall short of being scientifically literate (Templin & Bombaugh, 2005). Thus, it is critical to note that the current reform efforts advocated by the NSES require a substantive change in how science is taught. The key to making that change is through a reformation of teacher professional development practices in which educators participate in active learning that increases their knowledge, understanding, and ability (National Research Council, 1996).

As described above, science teachers are critical in helping students understand evolution. However, teachers, especially those teaching at the elementary levels, are under-prepared to teach evolution (National Research Council, 2007), have only a moderate understanding and acceptance of evolution (Nadelson & Nadelson, 2010), often avoid teaching it (Ashgar, Wiles, & Alters, 2007), and at times teach creationism too (Blank & Anderson, 1997).

This is particularly disconcerting because elementary school is where the foundations of scientific knowledge are laid; it is the most effective level for intervention leading to improved attitudes, higher achievement, and increased success in science for students (Rice & Corboy, 1995). Thus, the study of evolution, which is basic to the study of all biology, should begin in elementary school with the first introduction of life science to all students (Fail Jr., 2008). Evolution is often neglected in science curricula at all levels, especially the elementary grades (Alters & Alters, 2001). Waiting to teach evolution until students reach high school has not been an effective strategy, as a large percentage of the United States citizenry still does not accept or understand evolution (Nadelson et al., 2009). To help ensure that teachers develop scientifically-literate students, substantial amounts of time need to be invested in training teachers, especially elementary and middle school ones. Trainings should focus on teachers developing scientifically accurate understanding of evolution and learning effective methods for teaching students for conceptual understanding. Researchers are calling for studies to be conducted examining the effects of interventions on elementary and middle school teachers' understanding and acceptance of evolution, as few have been published in peer-reviewed journals. This dissertation study is designed to analyze the impact of such a training program on elementary and middle school teachers' understanding of evolution and how to teach the associated concepts.

Definition of Key Terms

Belief and acceptance. Differentiating between beliefs, which are held in the absence of objective evidence, and acceptance, which is based on the evaluation of evidence, is critical in understanding evolution and the nature of science, and how scientific knowledge differs from other ways of understanding the world (Smith, 1994; Southerland, Sinatra & Matthews, 2001). While some studies view the terms belief and acceptance to be interchangeable (Nehm, Kim, & Sheppard, 2009), others draw clear distinctions between the two (Sinatra et al., 2003). Southerland et al. (2001) contend,

> By using *acceptance of a theory as the best scientific explanation currently available,* one is emphasizing that the recognition of validity of a scientific theory is not simply a matter of personal opinion, thus providing a strong contrast with belief. (p. 341)

For the purposes of this study, beliefs are defined as a person's subjective ways of knowing. They are personal truths about the world, using personal conviction, opinion, and extrarational criteria (Nehm et al., 2009; Smith 1994; Southerland & Sinatra, 2003). Thus, when referring to a person's belief, or lack thereof, in evolution, those beliefs are based on the person's convictions, regardless of evidence from the natural world for or against them.

On the contrary, science is not about belief; it is about making inferences based on evidence. Thus, acceptance is defined as recognition of a concept's validity through rational and systemic evaluation of evidence (Nehm et al., 2009; Smith, 1994; Southerland & Sinatra, 2003). Thus, to say a person accepts evolutionary theory refers to the idea that the person thinks the theory accurately represents peoples' understanding of the natural world based on a critical evaluation of the evidence.

Microevolution and macroevolution. Evolution is a continuous process that unifies aspects of natural selection, environmental change, adaptation, time, chance and mutations (Miller, 1999). Though evolution is a single unified theory, there is a tendency in the evolution education literature and in peoples' minds to divide it into processes happening in the short term – microevolution, and processes happening in the long term – macroevolution. Throughout this study, microevolution refers to within-species variation or the genetic changes within and among populations, and macroevolution refers to the evolution of the higher taxa in all their diversity (Futuyma, 2005).

Pedagogical content knowledge. While teachers need to have an understanding of both the content they will be teaching and the pedagogical skills to teach those concepts, Shulman (1986) described another domain of knowledge, *pedagogical content knowledge* (PCK), which is critical for teachers to have. Shulman (1986, p. 7) explained PCK to be a unique form of subject matter knowledge explicitly for teaching; it includes knowledge of a specific subject area and "the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others."

Over the course of the more than 25 years since Shulman defined PCK, researchers continue to refine the precise, agreed-upon definition of the term. For the purposes of this study the definition of pedagogical content knowledge, as defined by Magnusson, Krajcki, and Borko (1999), is a teacher's understanding of how to help students comprehend specific subject matter. "It includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction" (Magnusson et al., 1999, p. 96). Magnusson et al. (1999) conceptualize PCK for science teaching to consist of five discrete components:

1. *Orientations towards science teaching,* refers to "teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (p. 97);
2. *Knowledge and beliefs about science curriculum*, refers to teachers' understanding of the goals and objectives for the subjects they are teaching, and knowledge of curricular materials relevant to the teaching of a specific domain;
3. *Knowledge and beliefs about students' understanding of specific science topics,* includes knowledge of prerequisite knowledge and skills needs for students to learn specific scientific concepts, and the identification of areas of science that students find to be challenging;
4. *Knowledge and beliefs about assessments in science,* including knowledge of aspects of science learning that are important to evaluate, and knowledge of methods that can be used to assess that learning; and
5. *Knowledge and beliefs about instructional strategies for teaching science*, including knowledge of both subject-specific and topic-specific strategies.

Purpose

The purpose of this study is to explore if and how an 11-month long teacher training program focusing on evolution affects elementary and middle school teachers' understanding and acceptance of evolutionary biology. It also investigates the effects of the training program on how teachers teach concepts related to macroevolution, and their understanding of students' conceptions about the topic.

Research Questions

Given the purpose of this dissertation, the specific research questions guiding this study are:

1. What is the effect of participating in a sustained professional development program on 4th through 8th grade teachers' understanding of macroevolution, particularly deep time, phylogenetics, speciation, fossils, and the nature of science?
2. What is the effect of participating in a sustained professional development program on 4th through 8th grade teachers' acceptance of evolution?
3. What is the relationship between 4th through 8th grade teachers' understanding of macroevolution and their acceptance of evolution?
4. How is 4th through 8th grade teachers' understanding of macroevolution related across three time points?
5. How is 4th through 8th grade teachers' acceptance of evolutionary theory related across three time points?
6. What is the effect of understanding of macroevolution on acceptance of evolutionary theory and the effect of acceptance of evolutionary theory on understanding of macroevolution across time?
7. What is the effect of a professional development series on teachers with varying levels of acceptance of evolutionary theory approach to teaching evolution in schools, awareness of challenges to teaching evolution, and pedagogical content knowledge about teaching macroevolution?

Significance of Study

Importance. Understanding societal issues including genetic engineering, antibiotic-resistant bacteria, and disease transmission requires understanding evolution theory (Nadelson, 2009). Biological developments often require public involvement for policy decisions, thus necessitating a scientifically literate populace. Citizens holding misconceptions about evolutionary theory may impede the ability to develop effective policy related to biological developments.

Lack of studies. In contrast with secondary teachers, elementary teachers are typically less supportive of the theory of evolution, believe that views other than evolution should be given equal time in the classroom, and believe that teaching evolution would lead to a breakdown of society (Blanks & Anderson, 1997). Furthermore, many kindergarten through 8th grade educators have low perceived levels of familiarity with evolution, and do not feel qualified to teach it. Teachers' acceptance of evolutionary theory may be the greatest issue impacting evolution education (Rutledge and Mitchell, 2002), as the importance of evolutionary theory to a teacher is a key predictor of the instructional approach taken toward teaching evolution (Deniz, Donnelly, & Yilmaz, 2002).

There are limited studies exploring the status of elementary and middle school teachers' understanding and/or acceptance of evolutionary biology, even though they are supposed to teach it. There are even fewer empirical studies examining the effects of an intervention on elementary and middle school teachers' acceptance and understanding of evolution. Researchers have recognized the lack of empirical work in this area and are calling for studies to be conducted on the effects of professional development programs on inservice elementary teachers' understanding of evolution (Asghar, Wiles, & Alters, 2007; Nadelson, 2009; Nadelson & Nadelson, 2010; van Dijk, 2009). Nadelson and

Nadelson (2010) call for the investigation, across a diverse population of teachers, of their attitudes, confidence in, and perceptions about teaching evolution. The reporting of empirical data from a broad spectrum of teachers is critical to determining perceived levels of personal preparedness and willingness to effectively teach evolution as part of their curriculum. This dissertation will make a substantial contribution to a field in which more studies are needed.

Existing studies focus on microevolution. The majority of studies exploring peoples' understanding of evolution focus on microevolutionary processes, while excluding macroevolutionary processes (Nadelson & Southerland, 2010). Research shows that the general public typically accepts microevolution, while rejecting macroevolution. Though the distinction between microevolution and macroevolution is artificial biologically, it may be an important psychological distinction, in that it may shape how individuals learn and understand biological evolution. Gaining an understanding of learners' knowledge of both processes may be critical as researchers describe how individuals come to understand evolution. This proposed dissertation adds to the field by focusing on teachers' understanding of macroevolutionary processes.

Need to design and evaluate interventions. Nehm and Schonfeld (2007) identify three core challenges facing evolution education. First, researchers and educators need to understand the interrelationships among cognitive, affective, epistemological and religious variables that contribute to antievolutionary views. Next, researchers and educators need to design, implement and evaluate interventions that promote accurate cognitive models of evolution. Lastly, overall levels of antievolutionary attitudes should be reduced. This dissertation study contributes to the understanding of evolution education by designing and evaluating a professional development series on elementary and middle school teachers' understanding and acceptance of evolution.

Study seeks to diminish the dearth of research. This dissertation is important because it responds to the current call for research to be conducted on the effects of a sustained professional development program on inservice elementary and middle school teachers' understanding and acceptance of evolutionary theory, particularly macroevolution. Additionally this study will explore the interrelationships among teachers' cognitive, affective, epistemological, and religious variables that affect their teaching of evolution.

Chapter Two: Literature Review

State and national level science standards call for evolution to be taught beginning in the elementary years (National Research Council, 1996). Despite this mandate, evolution is rarely taught and when it is, it is typically presented in high school biology. Waiting until high school to teach evolution has not been effective at developing conceptual understanding (Nadelson et al., 2009). Even after being taught scientifically accurate information about evolutionary concepts, people, even those formally trained in biology, still retain inaccurate conceptions about evolutionary processes (Bishop & Anderson, 1990; Brumby, 1984).

In order to understand evolution, people must undergo conceptual change in which their previous models of the world must be modified to create an entirely new way of understanding (Sinatra et al., 2008). Drawing on multiple models of conceptual change, Dole and Sinatra (1998) developed the Cognitive Reconstruction of Knowledge Model (CRKM). CRKM describes learning as a complex interaction among the learner's existing knowledge and motivation, the instructional message, and the learner's engagement with the message. As multiple variables combine to influence learning evolution, educators must be aware and take into consideration a variety of cognitive, affective, epistemological, and religious variables in order to promote conceptual change.

Evolution requires significant background knowledge to understand, suggesting that introducing the concept in elementary school may be critical to the development of deep understanding (National Academy of Sciences, 1998). Elementary and middle school teachers are required to take few undergraduate science courses to fulfill basic certification requirements (Fulp, 2002) and thus, often lack sufficient content knowledge to teach evolution effectively (National Research Council, 2007).Teachers without adequate subject matter preparation likely hold content misconceptions, and are likely to teach these misconceptions to their students (Jarvis, Pell, & McKeon, 2003). Professional development programs for inservice elementary and middle school teachers are vital to helping ensure these educators have sufficient depth and breadth in their understanding of evolutionary biology and how to teach it.

Theoretical Framework

Conceptual change. Without any formal training or schooling, people hold intuitive (Atran, 1998) or naïve theories (Evans, 2008) which provide a conceptual framework making it possible for them to make sense of the everyday world. These commonsense intuitions are those that first come to mind when people search for everyday explanations for natural phenomena. Intuitive reasoning may work well on a day to day basis; however, it causes difficulty in trying to understand concepts outside the realm of everyday experiences. For example, people intuitively hold that living things are separate, stable, and unchanging, and that animate behavior is goal directed and intentional (Evans, 2008). These intuitive reasoning patterns are in direct conflict with peoples' ability to understand evolutionary theory, as living things are variable and changing, and animate behavior is not directed toward a goal and is unintentional.

To help people understand evolution, educators must help them revise their previous models of the world to create an entirely new way of understanding (Sinatra et al., 2008). According to Evans (2008):

> We have to set aside or reconfigure our intuition that species were designed for a purpose, just like artifacts, and that they have unique essences. Specifically we have to switch from a naïve psychological explanation to a naturalistic explanation that eschews purpose and endorses the idea that living things undergo radical change. (p. 271)

The question becomes how can educators help students undergo such radical conceptual change? One proposed model theorizing how people undergo conceptual change is the Conceptual Change Model (CCM). The main tenet behind the CCM is that people learn by assimilating acquired information with what they already know or by reorganizing their existing concepts through accommodation to new ideas. To ensure that accommodation occurs, learners must: be dissatisfied with current conceptions, find the new conception intelligible and plausible, and understand why the new conception may lead to a fruitful research program (Beeth & Hennessey, 1996; Posner et al., 1982). In their original description of the CCM, Posner et al. (1982) explain that a learner's major organizing conceptions undergo a process of holistic change as new conceptions are judged to be more intelligible, plausible, and fruitful than the competing predecessors. In a subsequent article, Strike and Posner (1992) describe their original theory as overly rational and suggested that a learner's motivation and value of the subject matter play important roles in a learner's conceptual ecology. From a naïve theory perspective, conceptual change may consist of the elaboration of intuitive concepts rooted in a particular explanatory framework or a more sweeping shift from one intuitive theory to another to explain a specific phenomenon (Evans, 2008).

Building upon Posner et al.'s original work, Demastes, Good, and Peebles (1996) conducted 17 interviews with each of four high school Biology II students to investigate the patterns of student conceptual restructuring within the theoretical framework of evolution. They identified four patterns of conceptual change in their participants: cascade, wholesale, incremental, and dual construction. During cascade conceptual change, the change of one conception allowed a sequence of conceptual changes to occur. With wholesale change, which is similar to Posner et al.'s notion of holistic change, there is a restructuring of major organizing conceptions; thus, the prior conception is completely discarded in favor of a new conception based on the relative qualities of the evidence supporting the competing conceptions. In incremental conceptual change, which is similar to the notion of assimilation, students are using new terms within previously constructed explanations. Incremental change is important because students' preexisting conceptions change and serve as the basis for new conceptions. Students with dual constructions hold two incompatible conceptions.

Understanding that students may hold dual constructions is critical because that implies that the learning of scientific conceptions does not simply entail rebuilding of currently existing cognitive structures or a complete exchange of conceptions. Instead, learners can hold and apply two different conceptions. Casual flexibility, the capacity for people to shift explanations depending on context, is important to understanding how people conceptualize evolutionary biology (Poling & Evans, 2002). In their study of museum visitors, Evans et al. (2006) found that visitors' explanations of biological change in diverse organisms were inconsistent. Visitors' endorsement of evolutionary or creationist origins depended on the organism being discussed and whether the question was about microevolutionary change or macroevolutionary change. This study suggests that conceptual change is not only necessarily achieved by radically reconfiguring preexisting conceptual structures, but also by sidelining one particular conceptual framework in favor of another, as circumstances change.

Cognitive Reconstruction of Knowledge Model. Drawing on models of conceptual change from cognitive psychology, social psychology, and science education, Dole and Sinatra (1998) developed the Cognitive Reconstruction of Knowledge Model (CRKM) as a reconceptualization of the change process within a cognitive constructivist perspective. CRKM describes learning as a complex interaction among the learner's existing knowledge and motivation, the instructional message, and the learner's engagement with the message.

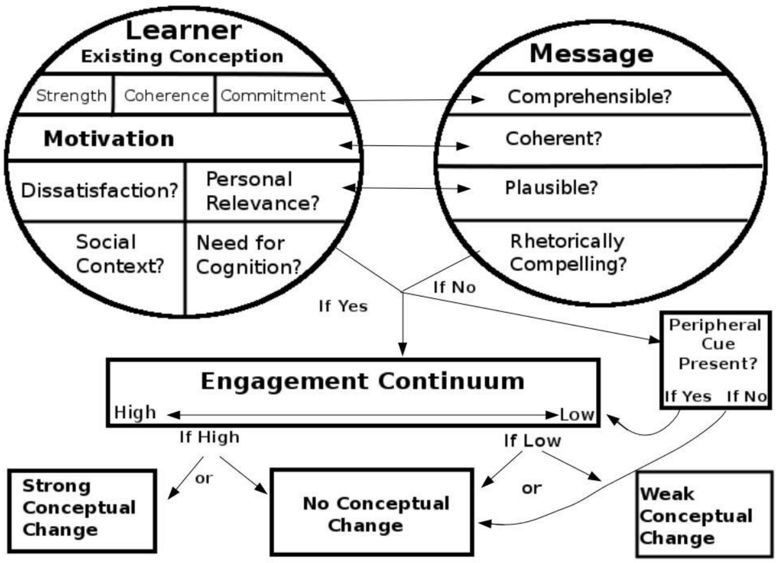


Figure 1: Cognitive Reconstruction of Knowledge Model (Dole and Sinatra, 1998).

CRKM begins with the interaction of the learner and the message characteristics. A key learner characteristic in the change process is existing conceptions regarding an idea, topic or phenomenon. Three relevant qualities of a learner's existing conception influencing the likelihood of change include strength, coherence and commitment. Strength refers to the richness of the person's existing ideas; coherence refers to the conceptual coherence of the person's existing knowledge; and commitment refers to their level of commitment to their existing idea.

Another critical characteristic of a learner is his/her motivation to process the new information. Individuals may be motivated to process the new information for multiple reasons. They may be dissatisfied with their existing conceptions, or the new information might have a personal relevance. The social context, including interactions with community members, school, or peer group, may motivate individuals to process information they would not previously consider. Lastly, some people are inherently motivated to process information.

Significant features of the message itself interact with the individual's existing conceptions and motivation to process a message. The message must be comprehensible to a particular individual. It cannot be too conceptually difficult and the individual must have sufficient background knowledge to relate to the message. The message must be considered plausible; thus, an individual must decide the message could be reasonably true. Learners must find the message to have a certain level of explanatory coherence in explaining the phenomenon. The message must be rhetorically compelling to an individual. Specifically, the language use, sources of information forming the argument, and justifications provided must be convincing and persuasive.

Dole and Sinatra explain that existing conceptions, motivation, and a specific message form an interactive, dynamic system; thus, the qualities of a message can only be considered as they interact with a learner's existing conceptions and motivation. Therefore, the learner characteristics and message effects are not linear; instead, the nature of the change process is iterative.

An individual will likely process new information if the interactions between the learner and message characteristics occur in a positive manner. Also interacting with the learner and message characteristics is how engaged a learner is with the message. The processing of information lies on a continuum from low cognitive engagement to high metacognitive engagement. The use of the term engagement "reflects a cognitive-constructivist view of information processing, strategy use, and reflectivity" (Dole & Sintra, 1998, p.121). Learners with low cognitive engagement may attend to information and process it through simple strategies requiring little reflective thought. New information may be assimilated into existing conceptions or remembered and compartmentalized, without changing existing conceptions. Thus, low engagement will often result in no, or weak, conceptual change. Learners involved in a high amount of cognitive engagement would use deep processing, elaborative strategies, and high levels of metacognitive reflection. It is through processing of information with high metacognitive engagement that strong, relatively long-lasting conceptual change may occur.

Even if individuals are not motivated to change and do not find the new information comprehensible or compelling, conceptual change may still occur. A peripheral cue can induce learners into low cognitive engagement which can then lead to a superficial change in conceptions, or high cognitive engagement that may lead to a more lasting conceptual change. For example, students listening to a lecture on evolution may not be motivated to learn more about the topic or committed to engage with the information at a high metacognitive level. However, these students may be persuaded to learn new information by a peripheral cue, such as learning information from a source they perceive to be attractive, credible, or trustworthy, or by being presented with a simple message they understand easily. The students are not convinced to undergo conceptual change by the strength of the arguments, but by the peripheral cue itself (Dole & Sinatra, 1998).

The CRKM is particularly applicable in exploring how people come to understand evolutionary concepts. Many complex and interwoven factors have resulted in the low understanding and acceptance of evolution in the United States. Hermann (2011, p. 274) explains, "Political, religious, social and educational influences have resulted in the perception that evolution is a controversial topic." Though there is consensus among scientists from many different fields that evolution is a robust, well-tested explanation for the history of life on Earth (American Association for the Advancement of Science, 2013), the general public continues to perceive evolution to be socially controversial (Hermann, 2008). Hermann argues that the combined effect of societal factors has led to the portrayal that science, particularly evolution, and religion are in direct conflict with each other.

Students are being exposed to evolutionary concepts, and the perceived evolution and religion controversy, well before high school, with experiences occurring in the early grades in the context of school, home, or church (Donnelly, Kazempour, & Amirshokoohi, 2008). Educators must be aware of and take into consideration a variety of cognitive, affective, epistemological, and religious variables in order to promote conceptual change (Sinatra et al., 2008). It is particularly important that educators consider all components of the CRKM when designing their evolution curriculum, including: (1) learners' existing conceptions, which may be in direct conflict with understanding and acceptance of evolutionary theory; (2) learners' motivation for learning about evolution; (3) learners' ability and willingness to find the evolution concepts comprehensible, coherent, plausible, and rhetorically compelling; (3) how engaged the learners are with the curriculum materials; and (4) peripheral cues which may impact how engaged they are with the presented material.

Science Standards

Scientific and educational organizations have recognized evolutionary theory as the ultimate framework for biology and say that the teaching of evolution is essential to students' understanding of biology (AAAS, 2006; NABT, 2008; National Research Council, 1996; NSTA, 2003). Evolutionary biology is a key component of the content standards in the National Science Education Standards (NSES). The NSES, one of the most influential science education documents in the United States, currently forms the backbone for state curriculum frameworks, programs, and assessment systems (Wagler, 2010). The NSES outlines content standards describing what science concepts students should know, understand, and be able to do at a particular grade level.

Understanding evolutionary processes requires not only knowledge of evolutionary content, but also comprehension of the nature of science, including the goals, methodologies, and principles of scientific endeavors. Thus, multiple NSES content standards are directly related to students' knowledge and understanding of evolution (National Research Council, 1996), including:

- Content Standard A, Science as Inquiry, specifies that kindergarten through 12th grade students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry.
- Content Standard C, Life Science, specifies that 5^{th} through 8th grade students should develop an understanding of structure and function in living systems, reproduction and heredity, regulation and behavior, populations and ecosystems, and diversity and adaptations of organisms. It also specifies that 9^{th} through 12th grade students should understand scientific concepts including the cell, molecular basis of heredity, biological evolution, and the interdependence of organisms as a result of classroom activities.
- Content Standard D, Earth and Space Science, specifies that 5th through 8th grades understand Earth's history, and 9^{th} through 12th graders understand the origin and evolution of the Earth system.

Wagler (2010) is critical of the NSES because they do not provide biological evolution standards for kindergarten through 4^{th} grades. He recommends lower grades' standards be revised to contain evolutionary concepts including: many kinds of organisms have lived or are currently living on earth; organisms are related to one another by a common ancestor that lived long ago and is now extinct; and organisms currently living on earth are continuing to evolve. While the NSES include concepts related to evolution to be taught to students in 5^{th} through 8^{th} grades, they do not directly call these principles evolutionary ones. The NSES do not introduce the term *evolution* or explicitly call for biological evolution to be included in the curriculum until students enter high school. Given the significant challenges educators face in helping students develop scientifically accurate understanding of evolution, waiting to directly introduce evolutionary concepts into the curriculum until students enter the 6^{th} grade may serve as a further barrier to understanding.

Since the publication of the NSES in 1996, significant advancements have been made in science and in our understanding of how students learn science. The Next Generation Science Standards (NGSS) were developed through a collaborative, state-led process to reflect these advances in science and the learning of science. The NGSS, which are based upon the National Research Council's (2011) *Framework for K–12 Science Education*, establish learning expectations for students that integrate three dimensions—science and engineering practices, disciplinary core ideas, and crosscutting concepts (Achieve, Inc., 2013b). The NGSS build science concepts from kindergarten through 12th grade and provide a description of the key scientific ideas and practices that all students should learn by the time they graduate from high school.

As of September, 2013, seven states, including Delaware, California, Rhode Island, Kentucky, Kansas, Maryland and Vermont, have adopted the NGSS (Achieve

Inc., 2013a). Thus, it is important to discuss how the NGSS address the teaching of evolution, particularly as more states are expected to adopt and implement the NGSS over the coming months and years.

Multiple NGSS are related to students' knowledge and understanding of evolution, including the following life science (LS) and earth and space sciences (ESS) disciplinary core ideas: (1) LS3, Heredity: Inheritance and Variation of Traits, particularly LS3.A, inheritance of traits; and LS3.B, variation of traits; (2) LS4, Biological Evolution: Unity and Diversity, particularly LS4.A, evidence of common ancestry and diversity; LS4.B, natural selection; LS4.C, adaptation; and LS4.D, biodiversity and humans; (3) ESS1, Earth's Place in the Universe, particularly ESS1.C, the history of planet Earth; and (4) ESS2, Earth's systems, particularly ESS2.B, plate tectonics; and ESS2.E, biogeology.

According to the NGSS, students would begin learning foundational concepts important to understanding evolution, such as comparing the diversity of plant and animal life in different habitats, beginning in the 2nd grade. However, the term *evolution* is not listed in the performance expectations, and thus, may not be explicitly presented to students, until the middle school grades. Wagler (2012) critiqued the *Framework for K–12 Science Education,* from which the NGSS were developed, in saying that the framework includes foundational concepts that can be built upon to understand specific biological evolution concepts, but there are no explicit references to evolution or mechanisms of evolution in the elementary grades. Thus, it is up to the individual teacher to decide if and how to introduce evolution in the kindergarten through 5th grades.

Teaching Evolution in the Early Grades

Similarly to the NSES and NGSS, many states include biological evolution curricula as a component of their science education standards (National Research Council, 1996). States are moving toward developing science education standards that are based on unifying concepts to reflect the multidisciplinary nature of science (National Academy of Science, 1998). Evolution is such a unifying concept as it integrates key concepts in biology, geology, chemistry, archaeology, genetics, and ecology (Gould, 2002). Until recently abstract scientific concepts, such as evolution, were rarely included in the elementary science curriculum.

Elementary years are where the foundations of science are laid. Because evolution is basic to the study of biology, its study should begin with the first introduction of biology to very young learners (Fail Jr., 2008). Evolution requires significant background knowledge to understand, suggesting that early exposure to aspects of evolution may be critical to the development of deep understanding (National Academy of Sciences, 1998; Wagler, 2012). Introducing evolution to young children is also important because this is a time when they are open to new ideas and are seeking evidence to test their hypotheses of how the world works (Nadelson et al., 2009). Through providing young children with experiences and activities that reflect scientific understanding of evolution, students are more likely to develop accurate conceptions upon which deeper understanding can be built. Furthermore, early exposure to related learning situations allows children to acquire knowledge and experiences which are essential for comprehending more abstract scientific concepts, such as evolution (National Research Council, 2007).

Children typically begin to reason in evolutionary terms beginning at approximately 8 years old (Evans, 2008). According to Evans' developmental analysis examining the early emergence of ideas about the origins of species in diverse communities, 5 to 7 year olds are more likely than older children to believe that animals are eternal and unchanging, and are unlikely to accept that animals undergo radical changes over their lifetime. However, 8 to 9 year olds are in a transition phase in which they are starting to confront existential questions, and understand within-species variation and change – the beginning of understanding of microevolution. They can integrate an understanding of proximate cause goal-directed actions, with more distal mental explanations. Depending upon the family belief system, 10-12 year olds are more willing to accept that one kind of animal could have descended from a different kind – the beginning of understanding of macroevolution.

How evolution is presented to young learners is an important element in helping students develop scientifically accurate understanding of evolution. In a series of three experiments, Harris et al. (2006) investigated which entities (e.g., germs, monsters, trees, tooth fairy) children four to eight years old thought existed and the basis for which they made the claim for their existence. The specific entities were chosen because, similar to evolutionary concepts which cannot be directly observed, they were ones in which children could make few, relevant firsthand observations due to physical or metaphysical limitations. The authors found that children's beliefs varied with the level of testimonial support they encountered about the existence of the entities, particularly from trusted sources such as parents. This study indicates that it is critical that elementary and middle school teachers, who students often consider to be trusted sources, present evolutionary theory in a positive light.

Evolution, when taught, is typically introduced in high school biology. However, waiting to teach evolutionary concepts until students are in high school has not been an effective strategy to develop conceptual understanding. Over the past 30 years, the percentage of Americans accepting evolutionary theory remained steady around 30 percent (Nadelson et al., 2009). The lack of significant change in acceptance and understanding of evolution implies that the current science education curriculum has not been particularly effective at teaching this theory. Thus, fundamental concepts in evolutionary biology should be taught to students beginning in elementary school to help them develop a deeper, more scientifically-aligned understanding of the topic.

Effects of Evolution Instruction on Promoting Scientifically Accurate Understanding

A variety of pedagogical and curricular strategies addressing peoples' understanding and acceptance of evolution have been developed (Nehm & Schonfeld, 2007) and implemented. The effectiveness of these strategies varies widely. The few studies that have been conducted with teachers will be presented first, followed by an examination of the more numerous studies conducted with students.

In Nadelson's (2009) study of 64 kindergarten through 12th grade teachers, participants read through four web-based tutorials from the *Understanding Evolution* website (www.understandingevolution.org) about misconceptions related to evolution and the nature of science, and then developed a lesson plan based on their reading. Teachers' lesson plans demonstrated that they still held and envisioned teaching misconceptions about evolution and the nature of science, despite the fact that many of the concepts were covered in depth in the tutorial.

The use of a simulated court case in which 48 undergraduate elementary education majors investigated intellectual, theological, and historical underpinnings of evolution and creationism, significantly decreased participants' agreement in Biblical creation, while increasing agreement that evolutionary biology is accurate (Helgeson et al., 2002). During the court case evolution and creationism were treated as neutral to show that: 1. an equal-handed approach was possible; 2. by combining science and social studies, teachers can study creationism through a historical perspective, and 3. students with firmly held opinions on both sides would be represented. Even with treating evolution and creationism as neutral, upon conclusion of the mock trial, preservice teachers favored evolution at the expense of creationism, and disagreed that the two competing views of the state of nature could be valid.

Several studies based on the conceptual change theory (see Posner, Strike, Hewson, & Gertzog, 1982) show that while instruction does increase student understanding of evolution, a significant number of misconceptions still persist post-instruction. In their study of 100 non-science major college students, Bishop and Anderson (1990) found that the percentage of students able to use scientific conceptions to explain evolution concepts increased from less than 25 percent on the pretest to over 50 percent on the posttest for each of the issues assessed after instruction based on the conceptual change theory. While students' alternate conceptions moved towards a more accurate scientific understanding, a significant number of students still did not have an accurate understanding of evolutionary processes.

In her analysis of 150 first-year medical students from Australia, Brumby (1984) found that after instruction only 21 out of 150 could accurately identify bacteria as the target of antibiotic treatment on a posttest. Alternate naïve notions held by the students included the idea that the body can become immune to antibiotics so they will be ineffective at treating illnesses, and that antibiotics can be prescribed to treat viral infections. Many of the students continued to hold the view that evolutionary change happens because organisms need to change.

Settlage (1994) studied 50 high school science students who were instructed using the Evolution and Life on Earth curriculum developed by the Biological Sciences

Curriculum Study. Students moved from having mostly teleological and Lamarckian based explanations for natural selection on the pretest, to more than half of the students responding on the posttest that natural selection is due to variation. While not all students stopped having naïve explanations for evolutionary processes, students did progress from having many naïve understandings toward a more accurate, scientific understanding. Settlage notes that students cannot be expected to develop complete understanding all at once. Growth in understanding is a developmental process, and he recommends extended exposure to key components of natural selection and other evolutionary concepts throughout the year.

The use of guided reinvention, in which students reinvent the concept of natural selection by answering a sequence of questions based on the logical nature of Darwin's theory, has been moderately successful at helping students gain scientific understanding of evolution (Geraedts & Boersma, 2006). During two, fifty-minute lessons instructors used a problem solving approach that systematically developed the concept of natural selection. The researchers posit that if the right questions are posed in the right order, and by providing the right background information when necessary, that students can reinvent the neo-Darwinian theory themselves. Seventy-two percent of the students demonstrated a Darwinian or neo-Darwinian conception on the post-assessment.

Passmore and Stewart (2002) designed a nine-week high school course in evolutionary biology, centered on engaging students in model use, to help them develop conceptual understanding of evolution. During the course, students were required to develop, use, and extend Darwin's model of natural selection while examining argumentation, language use, and scientific methodology. Preliminary data analyses indicated that through engaging in model use students had rich understanding of the natural selection model and were able to apply their reasoning about evolutionary phenomenon in discipline-specific ways.

The use of modeling can be an effective tool for students to understand about evolutionary concepts in other ways as well. For example, 5th grade students learned to reason about natural variation, a key component of natural selection, by generating, evaluating, and revising models of data recorded on Wisconsin Fast Plants (Lehrer & Schauble, 2004). Students grew the plants, designed experiments on growth factors, and collected measurements about the plants' changes over time. Students invented their own representational conventions and weighed the pros and cons of their representations. Working with student-generated graphical representations allowed students firm coordination between their knowledge of individual cases and their sense of aggregate numbers. This coordination is critical to understanding about variation between organism level and population levels as a tool for signaling biological growth processes.

The methods used to teach evolution are critical to helping students develop scientifically accurate understanding. Traditional teaching methods such as lectures in which learners are passive receivers of knowledge are not effective at helping students develop scientific understanding (Brumby, 1984). Instead, use of strategies such as integrating historically rich curriculum and paired problem solving into the classroom (Jensen & Finley, 1996), models (Lehrer & Schauble, 2004; Passmore & Stewart, 2002), guided reinvention (Geraedts & Boersma, 2006), and instruction based on the conceptual change theory have had positive effects on student understanding of evolution. While these strategies are more effective than traditional teaching methods in helping students understand evolution, many teachers have not been trained how to implement them effectively in their classes.

A consistent theme persists throughout the literature – students' understanding of evolution is not consistent with scientific understanding, and significant numbers of students hold misconceptions both before and after instruction. Thus, it is important to examine other aspects beside instructional strategies that may impact student understanding of evolutionary concepts.

Challenges to Understanding Evolution

There are many impediments to peoples' understanding of evolution including students' deeply held religious beliefs, confusing terminology, and misunderstanding the nature of science.

Naïve theories. One barrier to understanding evolution is peoples' naïve theories where experiences they have with the world further entrench their intuition and cause them to develop ideas about how the world works (Sinatra et al., 2008). People provide explanations for natural phenomena based on their intuitions that work well in everyday life, even if they are not scientifically accurate. The experiences that children have with the world further entrench their intuitive theories, and cause them to develop ideas about how the world works. For example, based on daily experiences, children think the Earth is flat. The idea of it being spherical and an object in space goes against their intuition and requires significant cognitive restructuring, similar to many evolutionary concepts.

Sinatra, Brem, and Evans (2008) identify three cognitive constraints that are problematic to student understanding of evolution: the essentialist constraint, teleological constraint, and intentionality constraint. The essentialist constraint explains that there is a tendency for people to believe that things belong to categories because they have an underlying nature that we cannot see, but that gives things their basic identity. This basic identity, their essence, is immutable. Thus, people find the evolution of one thing changing into another highly implausible (Rudolph & Stewart, 1998). Teleological constraints arise because people think things are made for a purpose (Jensen & Finley, 1996). Children innately hold that dogs have eyes and birds have wings because they need them. Thus, design-based accounts of living things are more plausible than evolutionary-based accounts. This need-based thinking, also known as Lamarckian-based thinking, is the predominant mode of thinking of students from middle school through college (Rudolph & Stewart, 1998). The intentionality constraint stems from students' assumptions that events are not only purposeful, but that they may be caused by an intelligent agent with a mind of its own. The notion of an intelligent agent conflicts directly with the nature of science in which scientific endeavors explain the natural world by gathering evidence and testing hypotheses.

Trying to counter these naïve theories can prove to be particularly challenging. According to Bloom and Weisberg (2007), the primary source of resistance to evolution instruction is related to what children know before they are exposed to science. In their review of the research on children's perceptions of trustworthiness, Bloom and Weisberg further concluded that resistance to scientific claims persists into adulthood if those claims are contested in society, and the resistance will be especially strong "if there is a nonscientific alternative that is rooted in common sense and championed by people who are thought of as reliable and trustworthy (p. 997).

The nature of science. Students have challenges understanding evolution because they do not understand the nature of science itself (Chuang, 2003; Nehm & Schonfeld, 2007; Nelson, 2008). Misconceptions persist about the nature of science often because students are not directly taught the concept. For example, colleges and universities frequently justify requiring non-science majors to take science courses to help students understand science as a mode of knowing or reasoning. However, science professors often find the scientific content to be so important that little consideration is given to teaching scientific reasoning and the nature of science (Nelson, 2008).

Misconceptions persist for other reasons too. People confuse methodological naturalism, the practice in science of restricting scientific inquiry to natural causes, with philosophical naturalism, which contends that matter and energy are all there is, and there are no supernatural entities of any kind. Students do not understand the clear delineation between the types of questions that science can and cannot answer, further perpetuating a perceived conflict between religion and science (Chuang, 2003). Thus, many people have become stuck in a false dichotomy thinking that the acceptance of evolution requires the rejection of a belief in God (Mead & Scott, 2010a).

Traditional science classrooms emphasize an experimental approach to science, where the goal is to establish laws which lead to experimental confirmation or falsification (Rudolph & Stewart, 1998). Rudolph and Steward (1998, p. 1078) argue, "Students come to view science and experiment in constant conjunction and fully expect that all assertions in science, if valid, should be capable of unambiguous demonstration."

Evolutionary biology does not fit well with this method. Many parts of evolutionary biology are historical sciences like geology and paleontology that strive to reconstruct phylogenetic relationships of the past and rely on indirect evidence. The key is to help students understand the types of, and robustness of, the evidence for evolution and to understand the experimental approach is not the only way to conduct scientific investigations.

Terminology. Terminology is often a barrier to student understanding of evolution (Bishop & Anderson 1990). For example, colloquially, to *adap*t means an individual's change in response to an environmental condition. Scientifically, to *adapt* means a population changing over many generations through natural selection. *Fitness* in everyday language refers to health and strength; scientifically *fitness* typically refers to the relative capacity of individuals to produce offspring. Consequently, students inaccurately apply their understanding of key concepts that are the foundation to understanding evolutionary processes. Furthermore, students do not understand the robustness of a scientific theory. A common misnomer is that evolution is “just a theory” meaning guess, when in fact theories are firmly grounded in and based upon evidence (Chuang, 2003; Nehm & Schonfeld, 2007).

The terms *chance* and *randomness* have extra-scientific meanings which often confuse students (Mead & Scott, 2010b). In science, the chance of something happening is to claim that it will occur according to a known probability; to know the probability of a phenomenon allows for the prediction of its occurrence. However, antievolutionists contrast evolution as the result of chance processes, with design and being the result of a plan or the purpose of a creator. Scientists use the word *random* to suggest unpredictability, while common understanding refers to random meaning purposeless. Teachers must be familiar with the extra-scientific understandings of these terms by their students so they do not unintentionally indicate to students that their religious views are incompatible with science.

Perceived impacts. People have negative perceptions about the social and personal impacts of evolutionary theory (Brem, Ranney, & Schindel, 2003) which may impede their understanding. Researchers examined how 135 undergraduates ranging on a continuum from strong creationists to strong evolutionists perceive the impacts of evolutionary theory on individuals and society. All groups had a negative outlook on the consequences of accepting evolution, including increased selfishness and racism, decreasing spirituality, and a decrease in the sense of purpose and self-determination. Furthermore, while controlling for belief, the more a person knew about evolution, the greater the perception of negative consequences. The majority of the students surveyed thought that both sides – evolution and creationism – should be taught to students to allow students to formulate their own beliefs (Brem, Ranney, & Schindel, 2003).

Griffith and Brem (2004) found that teachers worried about the perceived negative impacts of evolutionary theory and some experienced clinically measurable levels of stress when thinking about teaching evolution. Teachers handle their concerns in various ways, but usually their strategies reduced their ability to teach evolution and listen to students' concerns.

Relationship between knowledge and belief. Results of empirical studies on the effect of knowledge on belief or acceptance of evolutionary theory have been mixed (Bishop & Anderson, 1990; Demastes-Southerland, Settlage & Good, 1995; Lawson & Worsnop, 1992; Smith, 1994). Smith (1994) holds that students' lack of acceptance of evolution serves as a barrier to developing scientific understanding of it; thus, acceptance of the concept must be addressed before the learner can come to understand it. According to Nadelson and Southerland (2010), the probable interplay between understanding and acceptance of evolution makes the difficulties in teaching and learning about evolution all the more apparent. Conversely, Lawson and Worsnop (1992) claim that students' knowledge serves as a barrier to developing acceptance of evolutionary theory. Students cannot evaluate the strength of a theory until they have sufficient conceptual knowledge on which to base their judgment. Demastes-Southerland, Good, and Peebles (1995) found that instruction in evolutionary biology does not provoke a detectable change in students' acceptance of evolution; thus, it is possible for students to gain understanding without affecting their acceptance.

Microevolution versus macroevolution. The general public typically considers evolution to be referring to common descent, without understanding it also refers to changes in the gene frequency in a population (Poling & Evans, 2004). Though evolution is a single unified theory, there is a tendency to divide it into microevolution, which includes processes occurring in the short term, and macroevolution, which includes processes occurring in the long term. Some people have differing levels of acceptance and understanding of macroevolution and microevolution (Alters & Alters, 2001). These people more typically accept microevolution while rejecting macroevolution, or phylogenetic change.

If the lay public views microevolution and macroevolution as different, then the artificial distinction between the two processes may prove to be instrumental and fundamental to efforts to describe how individuals understand and accept evolution (Nadelson & Southerland, 2010). Though the distinction between the two processes is artificial biologically, it may be an important psychological distinction, in that it may shape how individuals learn and understand biological evolution. Gaining an understanding of learners' knowledge of both processes may be critical as researchers describe how individuals come to understand evolution. The bulk of prior research on peoples' understanding of evolution focused on microevolution. Thus, researchers have taken what is learned about peoples' understanding of microevolution and applied it more broadly to evolution. This research has overlooked the important differences in peoples' conceptions about microevolution and macroevolution. As researchers move forward, they should begin to clearly discriminate between microevolution and macroevolution when designing their research studies (Nadelson & Southerland, 2010).

Teachers' Knowledge and Acceptance of Evolutionary Theory

The importance of evolutionary theory to a teacher is a key predictor of the instructional approach taken towards evolution (Deniz, Donnelly, & Yilmaz, 2008). Rutledge and Warden (2000) surveyed 989 public high school teachers in Indiana and found a significant relationship between teachers' acceptance of evolution and their exposure to biology, evolution, and the nature of science. Furthermore, they found a significant relationship between acceptance of evolutionary theory and understanding evolution and the nature of science. Teachers only had a moderate acceptance of evolution, and understood evolutionary and nature of science concepts only moderately. Approximately 20 percent of the teachers surveyed were undecided about, or did not accept the scientific validity of evolutionary theory, that life is the result of evolutionary processes, the age of the Earth, or that evolution is supported by available evidence.

Teachers' acceptance of evolutionary theory may be the greatest issue impacting evolution education (Rutledge & Mitchell, 2002). There is an inverse relationship between teachers' strong religious convictions and their decisions about teaching evolution (Trani, 2004). Holding a religious explanation for the origin of species that contradicts evolutionary theory can interfere with teacher motivation and capacity to teach evolution in compliance with the state and national science standards (Nadelson, 2009). Deniz et al. (2008) explored the factors related to acceptance of evolutionary theory among preservice Turkish biology teachers using conceptual ecology for biological evolution as a theoretical lens. They found that thinking dispositions were significantly correlated with acceptance of evolution ($r = 0.27$, $p<0.01$). Thus, teachers with more cognitive flexibility and openness to belief change were more likely to accept evolution.

The more subject matter preparation in evolution and the nature of science teachers have, the more apt they are to accept evolutionary theory. Teachers' years of education and teaching experience influence their views of teaching and curriculum content (Pajares, 1992). These combined influences encourage teachers to teach how they were taught (Deemer, 2004) and to focus their teaching on the content they have studied (Alters & Nelson, 2002).

Rutledge and Mitchell (2002) explored the conceptions and knowledge structures of evolution held by teachers with varying levels of acceptance. Significant associations were found between acceptance of evolution and number of college credit hours taken in biology, taking a college course on evolution, and taking a college course on the nature of science. Significant associations were found between acceptance of evolution and classroom time devoted to it. Almost half of the teachers characterized their teaching as avoidance or briefly mentioning evolution, and one-third of the teachers spent less than three days on the topic.

Elementary teachers are often required to take few undergraduate science courses (Sinclair, Naizer, & Ledbetter, 2010). Most kindergarten through 8^{th} grade teachers are only required to take about two undergraduate science courses to fulfill graduation and certification requirements (Fulp, 2002). Thus, the demands on depth and breadth of kindergarten through 8th grade teacher knowledge are not typically attained through the fulfillment of basic certification requirements (National Research Council, 2007). This lack of science content knowledge causes teachers to lack confidence in their ability to teach science (Sinclair et al., 2010). If teachers do not feel prepared to teach a concept, they may reduce the amount of time spent teaching science, therefore reducing the probability of students mastering science education standards (Jesky-Smith, 2002). Teachers without adequate subject matter preparation, especially in evolution, likely hold content misconceptions. They are likely to teach these misconceptions to their students, thus impeding student conceptual development of scientific conceptions (Jarvis, Pell, & McKeon, 2003).

In their study of 138 teachers of grades kindergarten through 6th, Ashgar, Wiles, and Alters (2007) found that almost two-thirds of the teachers said that evolution was not covered or was poorly covered during their schooling. Almost one-third of the teachers said they would avoid teaching evolution or had reservations about teaching it in elementary school. Concerns they had about teaching evolution included parents' religion and opposition to evolution, conflict with creationism and science, the need for pedagogy for teaching evolution, lack of preparation to teach it, challenge in dealing with debate around evolution as a theory, lack of understanding of evolution, and that evolution goes against their own beliefs.

Secondary teachers are more supportive of the theory of evolution than elementary teachers (Blank & Anderson, 1997). In their study of 218 preservice elementary and secondary teachers, Blank and Anderson found that while more than half of elementary teachers do not believe in the theory of evolution and think that it is invalid, less than half of secondary teachers hold this view. Almost 90 percent of elementary teachers said other views besides evolutionary theory should be given equal time in the classroom, as opposed to approximately 60 percent of secondary teachers. More than half the elementary teachers held that the teaching of evolution would lead to a breakdown of society, while less than 15 percent of secondary teachers thought that.

Nadelson and Nadelson (2010) found positive correlations among teachers' perceived familiarity with evolution, qualifications to teach it, the importance of evolution to life sciences, and interest in learning more about it. Some kindergarten through 8^{th} grade educators had low perceived levels of familiarity with evolution, did not feel qualified to teach the concepts, and did not view evolution as important to learning life science. This was accompanied by a low desire to learn more about teaching it. Nadelson and Nadelson (2010, p. 855) explain:

> This evidence suggests that those educators that may have the greatest need for professional development in evolution education may not be interested in engaging in such activities. Yet, assuring that K-8 teachers have at least a fundamental familiarity of evolution, feel qualified to teach at least basic evolution concepts, and possess an awareness of the importance of evolution to learning life science, may be essential to meeting the goals of the K-8 science education standards.

While some teachers consciously limit or avoid teaching evolution, others directly teach creationism to their students. Moore (2004) found that 27 percent of Minnesota teachers attending a science conference thought it was legal to give equal time to evolution and creationism. According to a national survey of more than 926 public high school biology teachers, 13 percent of teachers surveyed teach creationism in their science classroom, 28 percent emphasize evolution, while the remaining 60 percent are neither strong advocates for evolutionary biology nor explicit endorsers of nonscientific alternatives (Berkman & Plutzer, 2011). Many of these teachers are either uninformed, or blatantly disregard legal issues associated with teaching evolution. Nehm and Schonfeld (2007) found that a majority of pre-certified secondary biology teachers, even after a 14-week intervention addressing misconceptions in evolution, still preferred antievolutionary ideas be taught in school.

If teachers are the key to creating a scientifically-literate society, substantial amounts of time need to be invested in training teachers to have scientifically accurate understanding of evolution and learning effective methods for teaching students for conceptual understanding. As Blank and Anderson (1997, p. 13) describe:

> As elementary teachers strive to fulfill the NRC goal of increasing the degree of science education in our elementary schools, the question of evolution must be considered. Will evolution be coming to a classroom near you when…a majority of preservice elementary teachers do not appear to accept evolution as a valid theory or to understand its basic tenets? Students could be receiving very different presentations of evolution as they travel along the academic pipeline. Could the groundwork elementary teachers lay early in a student's academic experience

> affect the student's perceptions and understanding of evolution enough that science instruction in secondary schools be dismissed? Could intervention in preservice education programs mitigate the situation?

Most colleges and universities do not require students to take an evolution course (Rutledge & Warden, 2000). Since there is a correlation between teachers' knowledge and acceptance of evolution (Deniz et al., 2008), the first step in increasing teacher knowledge is to require preservice teachers to take specific courses on evolution and the nature of science (Rutledge & Mitchell, 2002). To help preservice teachers accept evolution, Deniz et al. (2008, p. 493) recommend that evolution courses be taught through an "explicit, reflexive nature that models constructivist teaching principles by emphasizing the limits and tentative nature of scientific knowledge." Furthermore, these courses should include teaching practices such as integrating historically rich curricula into the classroom, guided reinvention, and paired problem solving.

While modifying the requirements of preservice teacher education to include additional science courses focusing on evolution is critical, so is providing in-service teachers with continual training to help further their understanding of evolutionary theory.

Professional Development

Kindergarten through 12th grade teachers are the most critical population for teaching an effective curriculum that increases students' knowledge of evolution while addressing misconceptions (National Research Council, 1996). However, most teachers hold positivist and transmissionist views of teaching which are contradictory to the teaching practices advocated by the NSES (Borasi & Fonzi, 2002), and these teaching views do not help students develop conceptual understanding of biological evolution. Issues with teacher preparation and attitudes towards science justify encouraging teachers to engage in professional development that focuses on science curriculum and instruction. Through participating in professional development, teachers may increase their knowledge, confidence, and understanding about teaching science concepts, thus making them more effective at teaching the content (National Research Council, 2007). A critical reform of teaching practices is needed to ensure that teachers are prepared to meet these new demands.

Professional development standards. Professional development programs are vital to address these learning needs and are the cornerstone for the implementation of standards-based reforms (Fishman, Marx, Best, & Tal, 2003). The National Research Council (1996) outlines four standards for teacher professional development, which include:

> Standard A: Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry.
> Standard B: Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching.
> Standard C: Professional development for teachers of science requires building understanding and ability for lifelong learning.
> Standard D: Professional development programs for teachers of science must be coherent and integrated. (pgs. 4- 5)

Fishman et al. (2003) note that at the heart of the science education standards is an inquiry-oriented approach to teaching and learning linked to pedagogical practices, such as constructivism and project-based learning. These reform-based teaching practices challenge the existing capabilities of teachers because they require changes in a teacher's classroom management strategies, the organization of knowledge and assessments, and require educators to have a much deeper and broader content knowledge than traditional teaching methods require.

Furthermore, teachers' beliefs and knowledge about teaching are often the direct result of their own experiences as learners, which generally conflicts with the reform-based practices called for in the NSES; thus, teachers need experience learning science under these new inquiry-based methods (Borazi and Fonzi, 2002). Reform-based professional development should focus on teacher learning and emphasize changes in the knowledge, beliefs, and attitudes of teachers that lead to the acquisition of new skills, concepts, and processes related to the work of reform-based teaching (Fishman et al., 2003).

Characteristics of effective professional development. Effective professional development programs are essential to help teachers develop the necessary knowledge and skills needed. Effective professional development is driven by a clear, well-defined image of effective classroom learning and teaching (Loucks-Horsely, Stiles, Mundry, Love, & Hewson, 2010). This well-defined image should be based upon research identifying how people learn best (Borasi & Fonzi, 2002), including focusing on student learning (Loucks-Horsely et al., 2010) and the use of cognitively guided instruction (Carpenter et al., 1989).

Professional development that promotes active learning is another characteristic identified as being part of effective professional development programs (Gess-Newcomb, 2001; National Research Council, 1996; United States Department of Education; 1999; Loucks-Horsly et al., 1996). Active learning can take a number of forms, including observing master teachers and being observed teaching; integrating new curriculum materials and new teaching methods into the classroom; reviewing student work in the topic areas being covered; and leading discussions and engaging in written work (United States Department of Education, 1999). The instructional methods used to promote teachers' learning should mirror the methods used with students (Loucks-Horsely et al., 1996).

Professional development opportunities should take teachers' knowledge, beliefs and attitudes into consideration (Loucks-Horsly et al., 2010). This is particularly important in designing professional development sessions around topics considered to be socially controversial.

Effective professional development emphasizes both content knowledge (Kennedy, 1998; United States Department of Education, 1999; Gess-Newcomb, 2001; Borasi & Fonzi, 2002) and pedagogical content knowledge (Kennedy, 1998; National Research Council, 1996; United States Department of Education, 1999; Loucks-Horsly et al., 1996). Thus, professional development programs should be planned as a coherent set of strategies to develop both content and pedagogical content knowledge, and help teachers select and integrate curriculum and learning experiences.

Science professional development should specifically focus on inquiry-based practices (Sinclair et al., 2010). The NSES define scientific inquiry as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of the students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996, pg. 23). Teachers must be taught inquiry teaching methods in order to be able to use the same pedagogy in their own classroom, as they often are not familiar with and/or have not conducted actual scientific inquiry.

Effective professional development fosters collaboration (Borasi & Fonzi, 2002) and builds or strengthens the learning community of science and mathematics teachers (Loucks-Horsly et al., 1996). More specifically, research encourages professional development that is designed for collaboration among groups of teachers from the same school, department, or grade level. Teachers who work together are likely to share common curriculum materials, course offerings, and assessment requirements; therefore, by participating in collaborative professional development, these teachers may be more likely to integrate what they learn with other aspects of their instructional content, sustain their practices over time, and help contribute to a shared professional culture (Gess-Newcomb, 2001).

Effective science professional development is led by facilitators with appropriate expertise (Loucks-Horsely et al., 2010) and fosters collaborations between scientists and teachers (Caton, Brewer, & Brown, 2000). Science classrooms remain one of the few arenas in which learning about evolution has the potential to take place. Science teacher educator and scientist collaborations are, therefore, central to fostering the development of teacher understanding of evolution (Nehm & Schonfel, 2007). Key components of scientist and teacher partnerships include: 1. bring together key partners to develop a common vision for the collaboration; 2. foster interaction between scientists and educators through experiences focusing on a shared vision and inquiry instruction; 3. develop curriculum resources that translate basic resources; 4. develop and pilot a series of inquiry-based "demonstration" curricula; and 5. implement a plan to sustain and expand the program to include new collaborative partners.

Effective professional development programs provide long-term coherent plans that are perceived by teachers to be a part of a coherent program of teachers learning (National Research Council, 1996; United States Department of Education; 1999; Loucks-Horsly et al., 1996). According to the United States Department of Education (1999), coherence can be judged in terms of: 1. the degree to which an activity builds on what teachers know and is followed up with other, more advanced coursework; 2. the extent to which the activity emphasizes content and pedagogy aligned with national, state, and local standards, frameworks, and assessments; and 3. the extent to which the activity supports teachers in developing sustained, ongoing professional communication with other teachers who are trying to change their teaching in similar ways. The coherence of professional development activities has an important positive influence on change in teaching practices. This suggests that teachers are more likely to change their practice if they experience professional development that is connected to other professional development experiences, is aligned with standards and assessments, and fosters professional communication.

Research calls for effective professional development to be time intensive (United Stated Department of Education, 1999; Supovitz & Turner, 2000). In their evaluation of Eisenhower-assisted professional development programs, the United States Department of Education (1999) found longer professional development activities tend to include substantially more opportunities for active learning; incorporate more aspects of coherence, including connections to a teacher's goals and experiences, alignment with standards, and professional communication with other teachers; and have a moderately positive influence on the emphasis given to content knowledge.

Supovitz and Turner (2000) used survey data to evaluate local systemic change professional development designed to increase teachers' abilities to teach science and math using research-based methods. Findings indicated that increased amounts of professional development were associated with greater use of inquiry and higher levels of investigative classroom culture. They found that teachers who participated in less than 40 hours of professional development had more traditional teaching practices (less use of inquiry) than the average teacher. It was only after 80 hours of professional development that teachers report using more inquiry-based practices than the average teacher.

In addition to the increased amount of professional development, sustaining the professional development over long periods of time is important too (United States Department of Education, 1999). Professional development sessions that persist over long periods of time are more likely to allow teachers the chance to try out new practices in the classroom and then obtain feedback on their teaching in order to further refine their practices. Additionally, the increased time span has a substantial positive influence on providing opportunities for active learning and coherence, both of which are characteristics of effective professional development and are discussed in detail below (United State Department of Education, 1999).

Several different professional development structures, including study groups, mentoring, teacher collaborative, committees or task forces, internship activities, action research, individually guided activities and workshops, have been evaluated in terms of being effective professional development strategies (Guskey, 2000; United States Department of Education, 1999).

Studies analyzing the effectiveness of professional development on enhancing inservice teachers' understanding of evolution and altering their teaching practices change are limited. Nehm and Schonfeld (2007) studied 44 pre-certified, inservice secondary biology teachers enrolled in a graduate science teacher certification program to evaluate the effects of a 14 week intervention on the teachers' understanding of evolution and their preferences for teaching evolution and/or creationism. Of the 44 teachers, 95 percent had a bachelor's degree or equivalent in life science. The course did significantly increase the teachers' knowledge of evolution and the nature of science, though misconceptions still persisted among some. Pre-course preferences for teaching evolution remained unchanged; the majority of the science teachers preferred that antievolutionary ideas be taught, and half of the teachers wanted some amount of creationism to be taught in schools. Nehm and Schonfeld suggest that perhaps there is a threshold effect where teachers have to have a much greater understanding of evolutionary theory before their preferences for teaching it are changed. In Nadelson and Nadelson's (2010) survey of kindergarten through 8th grade teachers who had completed a master's program in science education, many educators reported having a low familiarity with evolution, did not feel qualified to teach the concepts, and did not view evolution as important to learning life science. The results indicate that even having graduate level study in science education may not provide enough learning experience to prepare elementary and middle school teachers to teach evolution. "The potential for this condition supports the need for further professional development specifically focused on teaching and learning evolution related content" (Nadelson & Nadelson, 2010, p. 854).

Asghar, Wiles, and Alters (2007) found in their study of 138 preservice teachers of grades kindergarten through 6th that most of the preservice elementary teachers lacked a basic understanding of evolutionary biology. Nearly one-third of the teachers said they would avoid teaching evolution or had reservations about teaching it in elementary school. According to Asghar et al. (p. 206):

> The findings of this study corroborate the relevant literature's call for developing a better understanding of the basic concepts of evolution and fostering a positive attitude towards evolutionary science in pre-service elementary teachers through experience and evidence. This study further supports the need for appropriate pedagogical training of future elementary teachers to be professionally prepared to critically reflect on, and deal with, any challenges and pressures regarding the teaching of evolution in elementary schools.

Van Dijk (2009) interviewed nine teachers to examine their evolution-related pedagogical content knowledge. During the interviews, teachers reported they primarily focused on microevolutionary processes, especially mutation and selection. Furthermore, teachers assumed students' conceptions of evolutionary theory can be replaced with relative ease; an assumption that conflicts with current research on cognitive development related to evolutionary theory. Van Dijk recommends that teacher training focus on teachers' understanding of student's prescientific conceptions.

Summary

This dissertation builds upon prior research and helps address a critical issue facing the United States – the need for a scientifically literate populace. An important step in developing an informed citizenry is ensuring that teachers have the requisite knowledge and skills to help students develop understanding of key scientific concepts, especially evolution.

Elementary school is where the foundations of science are laid; since evolution is basic to the study of biology, its study should begin with the first introduction of biology to young learners (Fail Jr., 2008). However, though they are required to teach it, elementary and middle school teachers are underprepared to teach evolution and often hold misconceptions about the concept. Those misconceptions are often taught to students, further perpetuating the lack of understanding of evolutionary biology in the general public. Thus, it is vital that interventions designed to increase elementary and middle school teachers' understanding and effectiveness of their teaching of evolution are developed and evaluated. This study does so by evaluating the impact of a sustained professional development program on elementary and middle school teachers' evolution-related content knowledge and acceptance of evolution, and their approach to teaching it.

Chapter Three: Methodology

An expansion mixed methods research approach was employed in this study, using qualitative and quantitative data collection and analysis techniques in a sequential method (Greene, Caracelli, & Graham, 1989). The purpose for using an expansion design was to extend the breadth and range of inquiry by using different methods for different inquiry components. During this study, information learned from the quantitative portion of the study was used to inform the qualitative portion. Both data sets were then combined during the final analysis. This study was approved through The University of Texas at Austin's Human Subjects and Institutional Review Board, approved IRB protocol # 2010-08-0019.

Mixed methods research is defined as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (Johnson & Onwuegbuzie, 2004, p. 17). Mixed methods research design has both philosophical assumptions and methods of inquiry. According to Creswell & Plano Clark, 2007, p. 5:

> As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases in the research process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone.

According to Johnson and Turner (2003, p. 299), one of the main principles driving the use of mixed methodologies is to "elucidate the divergent aspects of a phenomenon." Combining both quantitative and qualitative methodologies in a single study allows researchers the ability to simultaneously answer confirmatory and exploratory questions, and verify and generate theory at the same time (Teddlie & Tashakkori, 2003). According to Greene and Caracelli (1997, as cited in Crewsell, Clark, Gutmann, & Hanson, 2003) the use of mixed methodologies can strengthen a study since: 1. multiple methods can neutralize the limitations of some methods; 2. qualitative research has been legitimized as a form of inquiry in the social sciences; and 3. great complexities exist in social phenomena, thus different kinds of methodologies are needed to best understand these complexities.

Participants

Participant recruitment. Participants were recruited to take part in the study using self-selective sampling techniques; they had to apply to participate in the program. See Appendix A for the application form. Participants were primarily recruited from the project's two partner organizations — a local Central Texas school district and one of the local Texas Regional Collaboratives for Excellence in Science Teaching (TRC), though other 4th through 8th grade teachers were able to apply to participate in the program. The local school district consistently records scores on state-wide science standardized tests significantly below the state average and enrolls a majority of students from historically under-represented populations in the sciences. TRC provides sustained Texas Essential Knowledge and Skills-based professional development to science teacher mentors who then return to their campus and provide professional development to their peers.

In October 2010, administrators from both partner organizations notified all 4th through 8th grade teachers in their programs via email about the opportunity to participate in the *Life Through Time Teacher Training Research Project*, as well as the instructions to apply for the program. Project staff purposefully chose to name and advertise the study as the *Life Through Time Teacher Training Research Project*, instead of using the term *evolution* in the title, in an attempt to avoid deterring teachers from applying who have a negative perception about the concept of evolution. In November 2010, study and application information was sent to other Central Texas school districts and science teacher organizations throughout Texas, asking them to disseminate the applications to their 4th through 8th grade teachers. Lastly information about the study was made available on the Texas Natural Science Center website, the project's sponsor.

There were a total of 20 available spots for participants in the study. The number 20 was chosen: 1. to allow for more one-on-one and small group interaction during the professional development program among project staff and participants; 2. because of financial constraints of implementing the project; and 3. because of space constraints in some of the field trip locations.

A total of 37 educators applied for the 20 spots in the study. Since more than 20 teachers applied to participate in the program, priority acceptance was given to teachers from the two partner organizations. All participants had to meet the following minimum criteria: teach 4th through 8th grades; teach a majority of students who are historically under-represented in the sciences, including Hispanics, African-Americans and females; and have a way to incorporate lessons related to key concepts in life through time in their classroom. Additional qualifications used to consider the acceptance of a teacher into the program included his/her years teaching experience, college coursework in the sciences, and responses to the open-ended questions about why he/she wanted to attend the program and how he/she would share the project curriculum with others. As I am fluent only in English, participants had to be able to speak, read, and write English fluently. Other factors such as age, gender, and ethnic background were not considered in analyzing the results of the study, and thus were not considered when selecting participants. All participants were of legal age and fully able to freely give consent for participation.

Two of the original 20 participants who were accepted into the program withdrew from participation after the first professional development session. Reasons for withdrawal were because of time conflicts preventing them from attending all of the subsequent professional development sessions, and because the teacher perceived the content of the first session to be more applicable to higher grade levels than the one she taught.

Participant demographics. Participants self-reported demographic information on their applications to participate in the study. Detailed demographic information for the study participants can be found in Table 1. Participants' years of teaching experience ranged from one year to more than 35 years, and one-third of participants had been teaching from 2 to 5 years. Two-thirds of the teachers taught elementary school. The vast majority of participants taught at a Title I school. All but one taught at a public school. Almost two-thirds of the participants held generalist teaching certificates, and majored in a non-science related major. The majority of the teachers did not hold a graduate degree. The total number of hours of science related college coursework taken ranged from 6 to 97 hours, and the average number of hours taken was 32. Teachers reported having more college hours in biology (18 hours) than any other science subject.

Table 1

Demographic Variables of Participants

Demographic variables	Frequency	%
Years teaching		
• 1 year	1	6
• 2-5 years	6	33
• 6-10 years	5	28
• 11-15 years	3	17
• 15-20 years	2	11
• 35+ years	1	5
Level(s) taught		
• Elementary	12	67
• Middle	3	17
• Elementary & Middle	1	6
• Middle and High	2	11
Title I school		
• Yes	14	78
• No	4	22
School type		
• Public	17	94
• Private	1	6
Teaching certification type		
• Generalist	11	61
• Science	7	39
Undergraduate major		
• Non-science field	11	61
• Science field	7	39
Graduate major		
• No degree	11	61
• Non-science field	5	28
• Science field	2	11
Hours of college science coursework		
• Avg. # of total hours	32	-
• Range of total hours	6 to 97	-
Avg. # of hours in		
• Biology	18	58
• Chemistry	5	16
• Physics	3	10
• Earth	3	10
• Space	2	6

Study Site

Much of the professional development sessions and all of the data collection took place at The University of Texas at Austin's Brackenridge Field Laboratory, an 82 acre, urban research station for studies in biodiversity, ecosystem change and natural history. In addition to participating in classroom-based sessions, participants went on field trips to scientific laboratories on The University of Texas at Austin campus — including the Texas Natural Science Center, both its museum and scientific collections, the Austin Core Research Center, and the High-Resolution X-ray Computed Tomography Facility, as well as fossil field locations in Central Texas.

Texas Natural Science Center's mission is to encourage the awareness and appreciation of the interplay of the biological, geological, and environmental forces as they have shaped, are shaping, and will shape our world. At the time of the study, the Center's exhibits and educational programs were located at the Texas Memorial Museum, a natural history museum with exhibits highlighting geology, paleontology, Texas wildlife, and evolutionary biology. The Center's research laboratories include the Vertebrate Paleontology Laboratory (VPL), Non-vertebrate Paleontology Laboratory (NPL), and Texas Natural History Collections (TNHC). The VPL is the principal repository for vertebrate fossils collected from state and federal lands in Texas and contiguous areas, as well as for specimens collected elsewhere using state and federal funds. The NPL's collections consist of four million non-vertebrate fossils, including invertebrates, fossil plants, gems, meteorites, and recent mollusks and corals collected throughout the world, but with an emphasis on Texas. TNHC's collections include more than 1.5 million specimens in the disciplines of ichthyology, herpetology, invertebrate zoology, and entomology. TNHC specimens were collected worldwide, but with special emphasis on Texas.

The Austin Core Research Center (CRC) is the Bureau of Economic Geology's main core repository for core and rock material donated to The University of Texas at Austin. The High-Resolution X-ray Computed Tomography Facility (UTCT) offers scientists the ability to use X-rays to create cross-sections of 3D objects, including rock, bone, or soft tissue. These cross-sections can be used to recreate a virtual model using nondestructive techniques. Fossil field locations included visiting the theropod and sauropod dinosaur tracks in the San Gabriel River outside Leander, Texas; off City Park Road in Travis County, Texas to explore marine fossils found in the Walnut Formation; and at McKinney Falls State Park in Travis County, Texas to explore an ancient ash bed.

Professional Development Model

The development of the series was based on: 1. Texas state science teaching standards related to the teaching of evolution; 2. evolution and nature of science education research literature; 3. an understanding of how to promote conceptual change as modeled by the Cognitive Reconstruction of Knowledge Model; and 4. the practices outlined in the preceding literature review describing characteristics of effective professional development programs. These concepts will be described in detail below. This project was supported in part by a grant from the Institute for Museums and Library Services Museum for America (Grant # MA-04-10-0171-10), as well as funds from the Texas Natural Science Center. Any views, findings, conclusions, or recommendations expressed in this dissertation do not necessarily represent those of the Institute of Museum and Library Services.

Project staff. Scientists and science educators developed and implemented the series to ensure the professional development content was based on current scientific understanding of evolutionary processes and aligned with research-based practices on how people learn. Primary project staff include: Dr. Pamela R. Owen, lead scientific consultant; Trish Jarrott, lead educator; Dr. Karen Ostlund, evaluation consultant; and myself. Owen, TNSC's senior paleontology educator, has expertise in both mammalogy and paleontology, and is particularly interested in the evolution of Carnivora — the order of mammals that includes wolves, dogs, cats, bears, weasels, and walruses. Owen has 24 years of teaching experience, including pre-kindergarten through college and continuing education programs. Owen and I co-developed the outline for the structure, pacing, and content of the series.

As lead educator, Jarrott was responsible for the day to day management of the project including assisting in recruiting participants, assisting in developing lessons for and co-leading the workshop sessions, and managing the web-based forum. Jarrott has 14 years teaching experience and during the project was the lead 8th grade science teacher at a local magnet middle school. She has a Master of Arts in Science Education, is a national trainer for the College Board, and is a presenter for Advanced Placement Strategies.

Through her role as evaluation consultant, Ostlund worked with other key project personnel to analyze workshop activities and teachers' evaluations, and suggest program improvements based on the academic content standards and participant feedback. Ostlund has more than 35 years of teaching experience. In addition to developing local, state, and national curriculum projects, she was the major contributor to *NSTA Pathways to the Science Standards: Guidelines for Moving the Vision into Practice, Elementary School Edition.* Dr. Ostlund attended the Evaluator's Institute, designed evaluation, and prepared reports for numerous funded projects.

Through serving as a participant observer, my involvement in the project varied. Not only did I oversee all aspects of the development and implementation of the professional development program, but I also taught lessons, worked with small groups, and observed the class while taking field notes.

Multiple scientists from the College of Natural Sciences and the Jackson School of Geosciences at The University of Texas at Austin served as guest lecturers throughout the series, and some reviewed workshop content for accuracy. A listing of the contributing lecturers and their areas of expertise during the time of the study follows.

- Ms. Sigrid Clift, outreach manager of the Bureau of Economic Geology, specializes in basic and applied research in fractured reservoirs using advanced imaging and structural petrology methods, stratigraphy, and petroleum geology.
- Dr. Mark Cloos, professor and Getty Oil Company Centennial Chair in Geological Sciences, focuses his research on studies of the structure, metamorphism, geochronology, sedimentation and seismicity at convergent plate margins.
- Dr. Travis LaDuc, assistant curator of herpetology, has more than 20 years of conducting herpetology and conservation presentations to school and civic groups around the southwestern United States, and continues his own research focusing on the biodiversity and natural history of Texas reptiles and amphibians, with emphasis on the population demographics of both blotched watersnakes and yellow mud turtles.
- Dr. Jessica Maisano, facility manager of the High-Resolution X-ray Computed Tomography Facility, is a collaborator on Deep Scaly, a project that is working to determine the evolutionary relationships among the major lineages of squamate reptiles.
- Dr. Ann Molineux, Non-vertebrate Paleontology Laboratory curator and collections manager, specializes in invertebrate paleontology and marine

paleoecology, and has particular interest in educating the public using paleontology collections.

- Ms. Laura Keffer, paleontology educator, conducts paleontology programs with kindergarten through college-aged students and teachers throughout Texas, and prepares vertebrate fossils in the TNSC's public *Paleo Lab.*
- Ms. Jessica Rosales Rains, ichthyology collections manager, conducts outreach programs throughout the year and is responsible for ensuring that specimens are legally accessioned into the fish collections, and properly curated.
- Dr. Edward C. Theriot, director of the TNSC and Roland Blumberg Centennial Professor in Molecular Evolution, studies the evolution of diatoms in the context of earth history.

Time intensive and sustained. Over the course of one year, participants attended a total of nine, day long training sessions: two, day long sessions were held in spring 2011, on February 12 and March 26; a five day institute was held in summer 2011 from June 13 through 17; and two, day long training sessions were held in fall 2011, on November 5 and December 10. Participants received a total of 65 hours of continuing professional education credit for attending the training — 35 of the 65 hours were approved by the Texas Association for the Gifted and Talented (TAGT) to count towards the TAGT Awareness Certificate in Science.

In addition to attending sessions, participants were expected to participate in an online forum, *Blackboard*, for one to two hours per month throughout the project. *Blackboard* is an interactive website allowing project staff and participants to communicate and collaborate through real-time chats, threaded discussions, class e-mail, and online file exchanges. The purpose of the online forum was to maintain sustained contact and develop a sense of collaboration among the participants and project staff throughout the project year. Participants responded to questions posted on the forum by project staff, and were expected to read and comment on their colleagues' posts. Questions posted by project staff asked participants to share ideas about resources and curriculum materials, ask questions of project staff and other participants, suggest lesson ideas, and read and reflect upon assigned material.

Though project participants were expected to contribute to Blackboard throughout the year, several problems prevented participants from contributing to the site as anticipated. For example, one teacher reported trouble logging onto the site one time, and gave up trying to contribute throughout the year. Another teacher reported that she read the assigned tasks on *Blackboard* and would read comments made by others, but did not contribute because she did not like to respond in public forums. Furthermore, mid-way through the program year, the group responsible for maintaining the project's access to *Blackboard*, The University's Information Technology Services, erroneously suspended all participants' access to *Blackboard* for an extended period of time. Prior to the suspension, contributors to the *Blackboard* site were able to view comments made by each participant and the name of the person associated with the comment. After the suspension, *Blackboard* deleted any names associated with the comments, and replaced the names with "anonymous". This error made it challenging for participants to continue their dialogues as they were not sure who said what statement, and made any analysis of the comments problematic as they were de-identified.

Workshop structure and content. The workshop content was based on: 1. themes in the life and earth sciences related to evolution from the Texas science education standards for 4th through 8th grades, as well as high school biology (Texas Education Agency, 2010); 2. concepts the evolution education research literature identifies as being particularly challenging for people to understand and/or accept, including human and chimpanzee relationships and deep time; and 3. additional concepts, such as how to interpret a phylogenetic tree, that project staff deemed important for teachers to understand about evolution, even though the teachers may not directly teach the concepts to their students.

Key scientific concepts covered during the series included: the nature of science; introduction to geology, including rock identification, the rock cycle, and geological processes; the fossil record and the roles of fossils in understanding of macroevolutionary change; deep time; plate tectonics; basic morphology and biodiversity of vertebrate groups; natural selection, animal adaptations; environmental change, evolution and extinction; and the Tree of Life. The order in which the concepts were presented was determined based on how challenging the subjects were to understand, the potential for the topic to be perceived as controversial by participants, and the availability of the guest lecturers to present specific topics to the group. Less-conceptually challenging topics, such as identifying rocks and the rock cycle, were presented first, and then progressively more challenging content was introduced. Project staff recognized that the topic of evolution may be perceived by some participants as contentious, and when introduced, could potentially cause the participants to focus on the perceived controversial nature of the topic as opposed to learning the new content. To help combat this potential problem, topics that project staff felt participants might perceive to be controversial, such as human evolution, were introduced later in the series after participants had a chance to get to know and feel more comfortable with one another and project staff.

Workshop sessions were co-taught by the scientists and science educators listed above in the Project Staff section. During each session, a scientist discussed his/her current research with the participants. Participants conducted inquiry- and specimen-based lab and/or field activities designed to deepen their understanding of the presented concepts and help teachers integrate the discussed concepts into their classroom curriculum. Participants received multiple curriculum guides and access to science teaching equipment and specimens to enable them to replicate the activities in their classroom through a lending program at TNSC.

Instruction. Embedded throughout the series was a focus on common misconceptions related to evolution and the nature of science, how to identify misconceptions their students have, and activities designed to counter these naïve notions. Time was given during each session for teachers to reflect upon their learning, and discuss topics brought up by both project staff and other participants. Topics discussed include how teachers could modify the activities for classroom use, and issues surrounding the teaching and learning of evolution-related concepts. Flexible grouping was used throughout the series, allowing participants to work individually, in collaborative pairs or small groups, or as a whole class, depending on the goal of the activity.

Data Sources

The current study used a variety of data sources from a data corpus that included: (a) applications to participate in the study; (b) written pre-, midpoint, and posttest content exams scores on the Measurement of Understanding of Macroevolution (MUM) assessment (Nadelson & Southerland, 2010); (c) written pre-, midpoint and posttest scores on the Measurement of the Acceptance of the Theory of Evolution (MATE) instrument (Rutledge & Warden, 1999); (d) interviews with select participants about the teaching of evolution in their classrooms; (e) reflections from the professional development series, (f) contributions to the web-based forum, Blackboard; and (g) evaluations of the professional development series at three time points. See Table 2 for a summary of the data sources collected as part of the study, and a listing of the sources included in the analysis. The timeline for the collection of these data sources and the intervention is summarized in Table 3. The rationale for the study's data sources is described below.

Table 2

Data Corpus and Sources Used for Current Study

Data Source	Used in Current Study?	Type of Analysis
Participant applications	Yes	Qualitative & Quantitative
MUM: pre/midpoint/posttest results	Yes	Quantitative
MATE: pre/midpoint/posttest results	Yes	Quantitative
Workshop reflections: completed after 7 of the professional development sessions	Yes	Qualitative
Interviews with select participants: pre-/post-instruction	Yes	Qualitative
Ongoing contributions to Web-based forum	No	Not applicable
Evaluations of the professional development series on Day 1, Day 7, and Day 9 of training	No	Not applicable

Table 3

Data Collection and Intervention Timeline

	Oct-Dec 2010	Jan-Feb 2011	Mar-Apr 2011	May-Jun 2011	Jul-Aug 2011	Sep-Oct 2011	Nov-Dec 2011
Intervention: Professional Development Series							
Participants attend 9 workshops		2/12	3/26	6/13-6/17			11/5 & 12/10
Data Collection							
Participants submit applications	10/12-12/21						
Pretest MUM & MATE		2/12					
Midpoint MUM and MATE				6/17			
Posttest MUM & MATE							12/10
Workshop session reflections		2/12 & 3/26		6/13, 6/15, & 6/16			11/5 & 12/10
Initial interviews with select participants			3/9/-3/25				
Post-series interviews with select participants							12/12-12/21

Participants' knowledge of macroevolution, as assessed by the Measurement of the Understanding of Macroevolution. Participants took pretests, midpoint, and posttests, consisting of both open- and closed-ended questions assessing their understanding of macroevolution on the first day of the training series, after the completion of the five-day summer institute, and on the last day of the series, respectively. The Measurement of Understanding of Macroevolution (MUM), the instrument used for the pretest measure, is comprised of 27 multiple choice items and one free response item. The MUM assesses the degree to which test-takers' knowledge conforms to the scientific understanding of facets of macroevolution (Nadelson & Southerland, 2010). The MUM was chosen for use in the study because of the high level of validity and reliability (Cronbach's alpha of 0.86) reported by Nadelson and Southerland (2010) and the questionnaire's measure of the understanding of macroevolution, with particular emphasis on deep time, phylogenetics, speciation, fossils, and the nature of science. Novik and Catley (2012) questioned the validity of the MUM in assessing test-takers' understanding of macroevolution because of inaccuracies and ambiguities they perceived to be presented in the measure. While a few minor editing changes were needed to the original MUM to improve the measure, the lead evaluation consultant, the lead scientific consultant, and myself agreed that the MUM was an adequate measure of peoples' understanding of macroevolution. The suggested editing changes were made prior to the administration of the pretest MUM.

To minimize test-retest bias and practice effects, two alternate forms of the MUM were created and administered at the mid- and posttraining time points. See Appendix B for the original MUM, and both alternate forms. The alternate forms were developed collaboratively by Dr. Karen Ostlund, the project's evaluation consultant; Pamela Owen, lead scientific consultant; and myself. Questions on the alternate forms covered the same concepts related to macroevolution (deep time, phylogenetics, speciation, fossils, and the nature of science) as originally assessed by the MUM, but included different taxa and questions specific to the morphology and/or behavior of the taxa. Except for the change in taxa and minor editing modifications, the wording, formatting and structure of the alternate forms were as close to the original MUM as possible.

Participants' acceptance of evolution, as assessed by the Measure of Acceptance of the Theory of Evolution. To examine teachers' acceptance of evolution, participants completed the Measure of Acceptance of the Theory of Evolution (MATE) questionnaire at three time points during the series: on the first day of the training series, upon completion of the five-day summer institute, and last day of the training series. The same questions were used each time the participants took the MATE, but the questions were reordered. The MATE, which consists of 20 Likert scale items, measures teachers' "overall acceptance of evolutionary theory by assessing their perceptions of evolutionary theory's scientific validity, ability to justify phenomena, and acceptance within the scientific community" (Rutledge & Warden, 1999, p.13). On the original MATE, participants responded to the five point Likert scale with responses ranging from "Strongly Agree" to "Strongly Disagree" to statements including, "The theory of evolution is incapable of being scientifically tested" and "The age of the earth is at least 4 billion years old." Possible scores ranged from 20, indicating a low level of acceptance of evolution, to 100, indicating a high level of acceptance. The MATE was chosen for use in the study because of the high level of internal reliability reported in previous studies (Cronbach alpha of 0.98 with high school teachers), the construct validation confirmed with high school biology teachers, and the questionnaire's measure of the acceptance of evolutionary theory (Rutledge & Warden, 1999).

In this study, the Likert-scale on the MATE was replaced with a continuous scale to allow for a more flexible response by participants. Using the continuous scale, as used by Arnold (1981), participants indicated their level of agreement with the statements on the MATE by drawing a line and stopping their pencil at the appropriate position along a pre-drawn 150 millimeter long line between “Strongly Agree” and “Strongly Disagree” to reflect their level of agreement. A copy of the modified MATE can be found in Appendix C. For each item, I used Mitutoyo Digimatic digital calipers to measure how long each participants’ line was along the pre-drawn line. That measurement was used as a participant score for that item. Scores per item ranged between 0 and 150.

I inadvertently wrote the continuous scale on each version of the administered MATE assessments in a reverse manner, such that participants who strongly agreed with a statement scored closer to 0, and those who strongly disagreed with a statement scored closer to 150. Thus, the higher the score, the less accepting of evolution the participant is. As the MATE is a measure of the acceptance of evolution, a higher score on the original MATE as administered by Rutledge and Warden (1999) indicated a person being more accepting of evolution. To be consistent with Rutledge and Warden’s analysis, prior to analyzing the data, I reverse-coded each participant’s item scores by subtracting each score from 150. Participants’ reverse-coded item response scores were then summed. Since the MATE is a 20-item assessment and participants could score up to 150 per item, possible scores ranged between 0 and 3,000 points indicating low and high levels of acceptance, respectively. For ease of interpretation, the point scores were then converted to a 100 percentage point scale.

Because the original MATE was scored on an 80 point scale, I converted the original MATE scale to the 100 point scale that this study employed. Thus, corresponding scores and categories for acceptance of evolution on the MATE using the modified continuous scale are: 86-100, Very High Acceptance; 71-85, High Acceptance; 56-70, Moderate Acceptance; 41-55, Low Acceptance; and 0-40, Very Low Acceptance.

Workshop reflections. Participants completed reflections at the end of seven of the nine total workshop sessions to gauge their thinking about the workshop content. On the reflections, participants were asked to respond to questions covering topics such as: the most important things they learned during the session, their understanding of the science concepts presented during the session, how they would address alternate conceptions with their students, what they will integrate into their classroom from the day, and lingering questions they still have. Specific reflection questions can be found in Appendix D.

Initial and posttraining interviews. Drawing on the literature reporting that teachers' acceptance of evolution has implications on their pedagogical decisions, formal, semi-structured qualitative interviews were conducted with eight of the total eighteen participants to probe both 1. how teachers with varying levels of acceptance of evolutionary theory differ in their views of learning and teaching evolution in elementary and middle school science; and 2. the effect of the professional development series on participants' pedagogical content knowledge related to teaching macroevolution.

Interview participants were purposefully selected based upon their acceptance of evolutionary theory score on the MATE. Three interviewees were selected from the participants who scored highest on the MATE and are in the Very High Acceptance group, three participants who scored the lowest and are in the Low Acceptance group, and three participants who scored in the mid-range and were in the Moderate Acceptance group. One of the three participants from the Moderate group withdrew from the study after the first training session; thus her interview results will not be presented. Detailed demographic information about the 8 interviewees will be presented in Chapter Five: Results.

Interviewees participated in two separate interviews, ranging from 35 to 60 minutes in length. Since the MATE was administered during the first training session, the first interviews took place in March, 2011 between the first and second professional development sessions. Post-course interviews were conducted upon completion of the professional development series in December, 2011. Interviews were conducted over the phone, and were recorded using the Olympus® Digital Voice Recorder WS-331M and a RaidoShack® Telephone Handset Recording Control.

During the initial interview participants were asked to describe the evolution-related concepts they teach, what they need to know to teach evolution, how they decide the concepts they teach, and what else they need to know to be able to teach evolution more effectively. Participants were also presented with scenario questions, as used by van Dijk (2009) and Kennedy, Ball, and MacDiarmid (1993), to study both challenges to teaching evolution and teachers' pedagogical content knowledge about teaching macroevolution, particularly the concepts assessed on the MUM - the nature of science, phylogenetics, deep time, speciation, and fossils. Through the use of scenarios, teachers were confronted with hypothetical scenarios meant to generate situations "in which the teacher would need to take into account both subject matter and learners" (Kennedy et al., 1993, p.11). The scenario questions were developed based upon assessment probes created to elicit preconceptions of fundamental concepts in evolutionary biology and the nature of science (Keeley, Eberle, & Dorsey, 2008; Keeley, Eberle, & Tugel, 2007), common examples of macroevolution (Diamond, Zimmer, Evans, Allison, & Disbrow, 2006; Vereecke, 2002), and alternate conceptions about evolution and the nature of science identified in the research literature (Trend, 2001; Understanding Evolution, 2010). See Appendix E for the interview protocol.

The primary purpose of the final interview was to explore if and how the professional development series impacted participants' understanding of and how to teach concepts related to macroevolution. During the final interview participants were again asked to describe the evolution concepts they teach to examine if teachers began teaching more evolution-concepts after attending the series, or if they were more aware of the evolution concepts they taught. Participants were asked about their perceived effect of the professional development series on their understanding and teaching of evolution. Additionally, scenarios were presented to explore challenges to teaching evolution and teachers' understanding of students' conceptions about macroevolution and how to teach it. The scenarios covered the same concepts related to macroevolution as in the initial interview - the nature of science, phylogenetics, deep time, speciation, and fossils – though different examples were used.

Methods of Data Analysis

Quantitative analysis methods were used to explore research questions 1 through 6, which explore participants' understanding of macroevolution and acceptance of evolutionary theory, while qualitative analysis methods were used to explore research question 7. Presented below is a description of the specific analysis methods used to answer each question.

Quantitative analysis procedures. Research question 1, which explores the effect of the professional development on teachers' understanding of macroevolution, was analyzed using participant outcomes on the MUM. I conducted a repeated measures analysis of variance (ANOVA) with one within-subjects factor (time) to compare the effect of the professional development series on participants' understanding of macroevolution on the pretest, midpoint, and posttest scores. All assumptions of the ANOVA were met prior to running the analysis.

Research question 2, which explores the effect of the professional development on teachers' acceptance of evolution, was analyzed using participant outcomes on the MATE. I conducted a repeated measures ANOVA with one within-subjects factor (time) to compare the effect of the professional development series on participants' acceptance of evolutionary theory on the pretest, midpoint, and posttest MATE scores. During preliminary analysis I observed that the reverse-coding of participants' acceptance scores caused the data distribution of the pretest, midpoint, and posttest MATE scores to be negatively skewed. I applied a *reflect and natural logarithmic* transformation to the data in an effort to normally distribute the data, and thus, meet the normality assumption of ANOVA. I also conducted the nonparametric Friedman's Test since the transformed data still violated the normality assumption. The Friedman's Test is a complete block analysis of variance which tests for treatment differences in a complete block design. Each block, or row, of the design is a subject. Each of the subject's scores is converted to a rank. The Friedman's Test then verifies if all column medians and means coincide with each other (Sardanelli & De Leo, 2008). The results of the ANOVA will be report in the results since the results of both analyses were equivalent.

Research question 3, which explores the relationship between teachers' understanding and acceptance of evolution, was analyzed using scores on the MATE and MUM. Prior to conducting my analyses I developed a theoretical path diagram, as recommended by Norman & Streiner (1998), to explicitly specify a presumed recursive causal ordering among the set of variables of interest. The path diagram in Figure 2 includes both participants' scores on the MUM assessment at three time points, and their scores on the MATE at three time points. Both understanding and acceptance are included to model the hypothesized relationship between the two constructs, and to allow for further exploration of the relationship between these two variables at multiple time points.

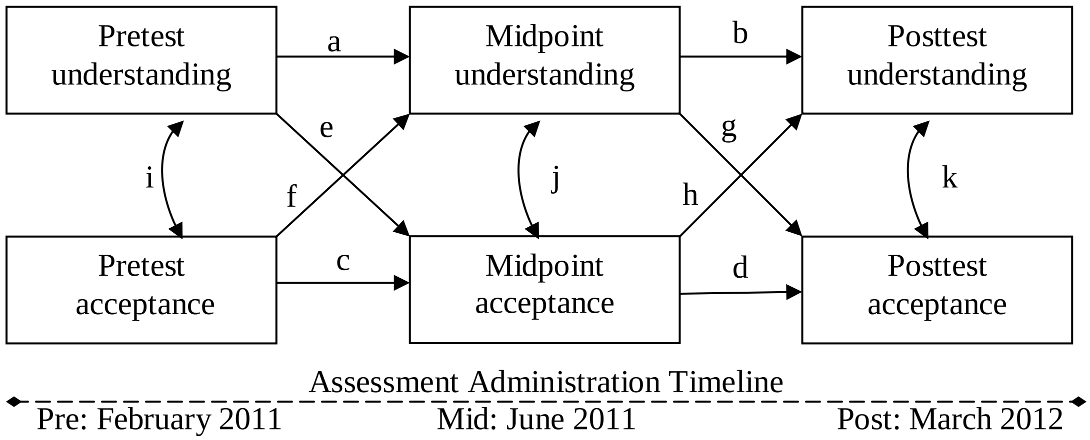


Figure 2. Theoretical path diagram: The relationship between understanding and acceptance of evolution across time. Variables in the path diagram are represented by rectangles. A direct effect is specified by a single-headed arrow drawn from an independent variable to a dependent variable. The direct effect is the hypothesis that a change in the independent variable will cause a change in the dependent variable. A double-headed, curved arrow indicates that variables are correlated.

I conducted Spearman's Rank Order correlations to test the hypothesis that teachers' understanding of macroevolution, as assessed by the MUM, and their acceptance of evolutionary theory, as assessed by the MATE, were related. I conducted correlation analysis, using both the original MUM scores and MATE scores, on: 1. path "i" in Figure 2 to examine the correlation between pretest MUM scores and pretest MATE scores; 2. path "j" to examine the correlation between midpoint MUM scores and midpoint MATE scores; and 3. path "k" to examine the correlation between posttest MUM scores and posttest MATE scores.

To analyze research question 4, I conducted both simple and multiple linear regression analysis to determine how teachers' understanding of macroevolution is related across the pretest, midpoint test, and posttest. Regression was used for this analysis, instead of path analysis as originally proposed, because of the relatively small sample size of the study. It is important to note that because of the small sample size of the study, more data points are needed to fully support the results of the multiple regression analysis. All assumptions of linear and multiple regression were met prior to conducting the analysis. I assessed the magnitude and significance, as estimated by the standardized regression coefficient, of the following linear regressions: 1. path “a” in Figure 2 to explore the relationship between pretest MUM scores and midpoint MUM scores, and 2. path “b” to explore the relationship between midpoint MUM scores and posttest MUM scores. I also assessed the magnitude and significance, as estimated by the standardized regression coefficient, of the multiple regression of the combined relationship of the pretest and midpoint MUM scores on posttest MUM scores.

To analyze research question 5, I conducted simple and multiple linear regression analysis to determine how teachers’ acceptance of evolutionary theory is related across the pretest, midpoint, and posttest. I assessed the magnitude and significance, as estimated by the standardized regression coefficient, of: 1. path “c” in Figure 2 to explore the relationship between pretest MATE scores and midpoint MATE scores; and 2. path “d” to explore the relationship between midpoint MATE scores and posttest MATE scores. I also conducted a multiple linear regression to explore the relationship of the pretest and midpoint MATE scores on posttest MATE scores. All assumptions of linear and multiple regression were met prior to conducting the analysis. I conducted the analysis using the transformed MATE scores to meet the normality assumption of regression. Since I reversed the original MATE scores and conducted a *reflect and logarithmic* transformation on the data, the resulting coefficients after running the analysis were negative, when they should actually be positive. For parsimony and ease of interpretation, I will present the untransformed coefficients in the results section.

To analyze research question 6, I conducted simple and multiple linear regression analysis to explore the effect of understanding of macroevolution on acceptance of evolution and the effect of acceptance of evolution on understanding across time. I used regression analysis to examine the magnitude and significance, as estimated by the standardized regression coefficient, of the following paths (see Figure 2): 1. path “f” to analyze the effect of pretest MATE scores on midpoint MUM scores, 2. path “h” to analyze the effect of midpoint MATE scores on posttest MUM scores, 3. path “e” to analyze the effect of pretest MUM scores on midpoint MATE scores, and 4. path “g” to analyze the effect of midpoint MUM scores on posttest MATE scores. Additionally, I also conducted multiple regression to analyze the effect of: 1. midpoint MATE and MUM scores on posttest MUM scores, 2. midpoint MATE and MUM scores on posttest MATE scores, 3. pretest MATE and MUM scores on posttest MUM scores, and 4. pretest MATE and MUM scores on posttest MATE scores. All analyses were conducting using the transformed MATE data, and the untransformed coefficients will be presented in the results. All assumptions of linear and multiple regression were met prior to analysis.

Consistent with mixed methodology design principles calling for qualitative and quantitative data to be integrated within a study (Johnson & Onwuegbuzie, 2004), I used multiple data sources, including the interviewees’ applications, interviews, reflections, and scores on the MATE and MUM, to analyze research question #7. The goal of merging the qualitative and quantitative data is to elicit a rich story about participants' understanding, acceptance, and teaching of evolutionary theory by tapping into participants’ unique experiences and perspectives associated with evolutionary biology.

After completing each interview, I transcribed it verbatim using Microsoft Office Word 2007. I also digitized each participant’s responses on the applications and reflections by typing their handwritten responses into Microsoft Word 2007. I then imported the transcriptions and digitized responses into NVIVO Qualitative Analysis software for coding.

Qualitative data sources were analyzed using the Corbin and Strauss (1990) grounded theory approach. Consistent with their recommendations, analysis began upon collecting the first piece of data and continued throughout the data collection process. Data was first open coded to develop categories of concepts and emerging themes. Hierarchical coding categories from the data sources related to the effect of the professional development series on participants' with varying levels of acceptance of evolution approach to teaching evolution, perceived challenges to teaching evolution and responses to those challenges, and pedagogical content knowledge about teaching macroevolution were identified using the constant comparative method (Glaser & Stauss, 1967). These hierarchical coding categories provide a framework from which to describe the effect of the professional development on participants' teaching of evolution. I conducted multiple iterations of coding of each participant's data sources, and then developed a detailed profile of each participant from multiple data sources. Multiple data sources, which were collected over approximately a one year time period, were used in the analysis to triangulate the data to help further identify patterns and develop explanations. The participant profiles were then used to compare and contrast teachers both between and within the different evolution acceptance groups in terms of the effect of the professional development on their approach to teaching evolution, awareness of challenges of teaching evolution, and pedagogical-content knowledge about concepts related to macroevolution. While I conducted all data analysis by myself, I am currently working with another evolution education researcher to ensure the inter-rater reliability of the study's data.

Participants' approach to teaching evolution was analyzed by comparing initial and post-session responses in terms of: 1. how the participant decided what evolution-related concepts he/she would teach, 2. the evolution-related concepts he/she taught; and

3. methods used to teach evolution. Emergent themes, which are presented in Tables 4 and 5, were identified from the participants' responses and were member checked for accuracy. The challenges to teach evolution were analyzed according to: 1. participants' acceptance of evolutionary theory, 2. their perceptions of the most challenging aspects regarding teaching evolution, and 3. their response to probes about how evolution was taught in their class. See Tables 6 and 7 for the emergent themes from these constructs, which were member checked for accuracy. Next, in order to examine the effect of the professional development on participant's pedagogical content knowledge about macroevolution, particularly the nature of science, fossils, phylogeny, speciation, and deep time, interviews and reflections were reviewed and further coded according to each teacher's emergent themes from these constructs. See Tables 8 and 9 for emergent themes from the pretraining interviews. See Tables 10 and 11 for emergent themes from the posttraining interviews and reflections. These emergent themes were also member checked for accuracy.

Table 4

Summary of Participants' Pretraining Approach to Teaching Evolution Themes According to Coding Construct

<table>
<tr><th colspan="3">Coding Constructs for Approach to Teaching Evolution: Pretraining</th></tr>
<tr><th>Deciding what to teach</th><th>Evolution concepts taught</th><th>Methods used to teach evolution</th></tr>
<tr>
<td>
based on own learning preference
based on the TEKS
collaborated with colleagues
focused on standardized test preparation
used a scope and sequence
used the National Lutheran School Accreditation Standards
</td>
<td>
adaptation
cosmology/big bang theory
Charles Darwin & the theory of evolution
deep time
does not cover/avoids teaching portions of evolution topics
fossil record
human and chimpanzee relatedness
inherited and learned traits
natural selection
nature of science
presented through a creationist perspective
TEKS do not require the teaching of evolution
speciation
</td>
<td>
parental involvement

encourage parent to discuss beliefs with student
show parents content being taught

role of science and religion

differentiate between science and religion
incorporate creationism
science and religion can co-exist

teaching method

allow student to be pulled from class
bring up evolution whenever possible
directly address misconceptions
does not cover evolution in depth
does not know how to address
encourage students to have an open mind
focus on standardized test preparation
incorporate evolution whenever possible
microevolution occurs, but not macroevolution
prepare students to take a side
present topic in neutral light
questions how to address evolution
say "distinctions in time"
science is perceived to be a less important subject
teach concepts at an introductory level
teach concepts in isolation
use rich discussions

</td>
</tr>
</table>

Table 5

Summary of Participants' Posttraining Approach to Teaching Evolution Themes According to Coding Construct

Coding Constructs for Approach to Teaching Evolution: Posttraining		
Deciding what to teach	**Evolution concepts taught**	**Methods used to teach evolution**

▪ based on the TEKS
▪ collaborated with colleagues
▪ focused on standardized test preparation
▪ has flexibility in teaching
▪ no longer teaches science
▪ used a scope and sequence
▪ used the National Lutheran School Accreditation Standards
	▪ adaptation
	▪ basic introduction to evolution
	▪ classification and identification of organisms
	▪ deep time
	▪ did not have time to incorporate LTT lessons
	▪ fossil record
	▪ had not taught lessons yet
	▪ natural selection
	▪ nature of science
	▪ phylogeny
	▪ presented through a creationist perspective
	▪ theory of evolution
		▪ incorporated materials and/or resources from the training series
		   ▪ adaptation activities
		   ▪ deep time materials
		   ▪ dichotomous key activity
		   ▪ field experiences
		   ▪ fossil record activities
		   ▪ looks forward to implementing materials
		   ▪ marked literature connections
		   ▪ nature of science activities
		   ▪ phylogeny activities
		   ▪ speciation activities
		   ▪ technology connections
		▪ role of science and religion
		   ▪ differentiate between science and religion
		   ▪ incorporate creationism
		   ▪ teach uncertainty
		▪ teaching method
		   ▪ allow students to call evolution another name
		   ▪ connect to students' experiences
		   ▪ cover multiple scientific contributions to plate tectonic theory
		   ▪ directly address misconceptions
		   ▪ should evolution be taught in school discussion
		   ▪ does not cover topics in depth
		   ▪ does not know how will introduce
		   ▪ encourage students to have an open mind
		   ▪ encourage students to talk with parents
		   ▪ focus on standardized test preparation
		   ▪ integrated scientific disciplines using LTT resources
		   ▪ integrated subject areas or scientific disciplines
		   ▪ unable to teach concepts because removed from science teaching

Table 6

Summary of Participants' Pretraining Challenges to Teaching Evolution Themes According to Coding Construct

Coding Constructs for Challenges to Teaching Evolution: Pretraining		
Belief in evolution	**Most challenging aspects**	**How evolution is taught**

▪ believes in parts of evolution, but not others
▪ no definitive answer, but it is based on science
▪ remain neutral
▪ yes
▪ yes, but differentiates between belief and acceptance
▪ yes, but God had role in process
	▪ content challenges
	  ▪ challenges understanding macroevolution
	  ▪ challenges understanding microevolution
	  ▪ challenging vocabulary
	  ▪ concepts are abstract
	  ▪ students do not accept human evolution
	▪ other teachers do not teach similar content
	▪ perceived conflict between evolution and religion
	  ▪ conception that evolution is wrong
	  ▪ concerns about voicing creationist perspective
	  ▪ emotional idea that humans evolved from animals
	  ▪ parts of evolution are refutable, but others are not
	  ▪ perception there are negative consequences to believing in creationism
	  ▪ presenting content without offending students
	  ▪ students dismiss the concept because they do not believe in it
	▪ role of parent
	  ▪ does not want to go against parental teachings
	  ▪ parental concerns about teacher forcing student to believe in evolution
	▪ school is not supportive of teaching evolution
	▪ student background
	  ▪ knowledge base is limited
	  ▪ mobile student population
	  ▪ takes bilingual students longer to process information
	▪ teachers have limited science background knowledge
	▪ the TEKS
	  ▪ political resistance to teaching evolution in Texas
	  ▪ unsure how to address evolution
		▪ allow student to be pulled from content
		▪ communicate with parents
		  ▪ ensure parents know teacher's bias in presenting creationist material
		  ▪ provide an overview of the nature of science
		  ▪ invite parent to attend class where evolution is taught
		▪ explain student needs to understand evolution to be scientifically literate
		▪ explain that evolution and religion can co-exist
		▪ explain that evolution is a robust theory
		▪ explain the concepts are part of TEKS
		▪ explain the focus of the class is on adaptations
		▪ explains teacher is there to teach facts, but theories can change
		▪ presents both creationism and evolution
		▪ says does not teach evolution
		▪ says is not teaching that evolution is right or students should believe in it
		▪ summarize how evolution is approached in class
		▪ teaching science concepts, which are based on evidence

Table 7

Summary of Participants' Posttraining Challenges to Teaching Evolution Themes According to Coding Construct

Coding Constructs for Challenges to Teaching Evolution: Posttraining		
Belief in evolution	**Most challenging aspects**	**How evolution is taught**
▪ believes in parts of evolution, but not others ▪ no definitive answer, but it is based on science ▪ remain neutral ▪ yes ▪ yes, believes in both science and religion ▪ yes, but differentiates between belief and acceptance based on LTT activity	▪ content challenges ▪ challenges understanding macroevolution ▪ challenging vocabulary ▪ persistent misconceptions ▪ too complicated for people to understand ▪ lack of materials to teach labs ▪ lack of parental support ▪ perceived conflict between evolution and religion ▪ no one really knows what occurred ▪ not all aspects of evolution are irrefutable ▪ perception that evolution and belief in God cannot co-exist ▪ perception that learning about evolution has negative consequences ▪ religion is taught from birth, not evolution ▪ understanding without acceptance ▪ student background ▪ students are academically advanced ▪ students are not motivated ▪ students are not used to labs or participating in activities ▪ students are not used to reading about science ▪ student have limited experience with higher order thinking ▪ students' knowledge base is limited ▪ students resist new things ▪ students want to hold onto their beliefs ▪ teacher frustrations ▪ teachers have limited science background knowledge ▪ teaching is overwhelming ▪ things keep changing ▪ time limitations ▪ the TEKS ▪ perceives evolution content is not part of TEKS ▪ TEKS require bare minimum to be taught	▪ allow students to call evolution "adaptation" instead because the two are the same concept ▪ differentiates between science and religion ▪ encourage parents to discuss beliefs with student ▪ explain theories are based on evidence ▪ new discoveries may disprove evolution ▪ not telling students what to believe, just presenting evidence ▪ teacher explains she does not really teach evolution ▪ teaching what scientists feel is correct ▪ teaching what the state decided would be taught ▪ tell students they do not have to believe in evolution ▪ tell students they have to understand evolution, not believe in it

Table 8

Summary of Participants' Pretraining Macroevolution PCK Themes According to Coding Construct

Coding Constructs for Pedagogical Content Knowledge about Macroevolution: Pretraining		
Nature of Science	**Fossils**	**Phylogeny**

▪ ask students to define *theory*
▪ evolution can become more than a theory
▪ differentiate between scientific and colloquial definitions of theory
▪ evolution is not "just" a theory
▪ give student definition
▪ science can be proven right
▪ theories explain how something works in nature
▪ theories are speculative
  ▪ evolution is "just a theory"
  ▪ scientists do not know everything yet
  ▪ scientists may learn something completely different than the theory
  ▪ theories are based on observations but have not been proven
  ▪ theories can be revised with new information
  ▪ theories can change when God allows for further exploration
  ▪ new knowledge may disprove or support evolution
▪ theories are robust
▪ theories are proven
▪ theories based on evidence
	▪ fossil could have been brought by other organism
	▪ fossilization takes a long time
	▪ land was previously covered with water, and earth's surface changed over long periods of time
	▪ show or reference fossils of ocean organisms found on land
		▪ cladogram shows
		  ▪ ancestors weren't human
		  ▪ human cladogram is based on limited data
		  ▪ humans and apes originated from a common ancestor
		  ▪ humans are most closely related to chimps & bonobos
		  ▪ relatedness of different species
		  ▪ speciation event
		  ▪ teachers teach from creationist perspective
		  ▪ uses evidence from different areas to support hypothesis
		▪ evidence for cladogram is based on/supported by
		  ▪ behavior
		  ▪ genetic evidence
		  ▪ fossils
		  ▪ morphological characteristics
		  ▪ organs
		  ▪ social evidence
		  ▪ unspecified characteristics
		▪ humans are on the right of the cladogram because
		  ▪ they share characteristics with bonobos
		  ▪ does not know why
		  ▪ does not think humans share features with gibbons
		  ▪ for no reason
		  ▪ of reading conventions
		  ▪ nodes can change
		  ▪ people think they are smartest/most recently evolved
		  ▪ they share characteristics with bonobos
		  ▪ they were the last to evolve
		▪ relationship of chimpanzee and bonobo indicates
		  ▪ bonobo branched off chimp line
		  ▪ bonobo is newer discovered
		  ▪ bonobo started as chimp, then adapted, now is different species
		  ▪ they are closely related
		  ▪ they are off same branch because split into 2 groups
		  ▪ they are similar looking

Table 9

Summary of Participants' Pretraining Macroevolution PCK Themes According to Coding Construct, Continued

Coding Constructs for Pedagogical Content Knowledge about Macroevolution: Pretraining	
Deep Time	**Speciation**

▪ conceptual challenges
  ▪ events happened before students were born
  ▪ students cannot see events happening
  ▪ students do not have concept of large numbers, scale, or scientific notation
  ▪ students do not have knowledge base of ancient organisms
  ▪ students do not have much life experience
  ▪ students do not understand long length of time
  ▪ teacher questions validity of radiometric dating
▪ methods to teach concept
  ▪ emphasizes past events shape landform changes
  ▪ use timeline analogy
  ▪ uses lab about erosion, deposition and fossils
  ▪ uses topographic maps to show landform changes
  ▪ uses pictures instead of actual fossils
  ▪ uses United States Geological Survey charts
  ▪ would teach using visuals and graphic organizers
▪ teacher does not cover time in depth
▪ teacher is not sure what deep time is
	▪ emphasis on change within a kind
	▪ emphasis on form and function
	▪ emphasis on geographic or reproductive isolation activity
	▪ emphasis on how environment shapes animal's adaptations
	▪ emphasis on limited natural resources or food choice affects what birds eat
	▪ emphasis on natural selection
	▪ emphasis on organism being able to hide from predators
	▪ emphasis on organisms having to adapt to changes
	▪ questions how TEKS require teaching of Galapagos Islands

Table 10

Summary of Participants' Posttraining Macroevolution PCK Themes According to Coding Construct

Coding Constructs for Pedagogical Content Knowledge about Macroevolution: Posttraining		
Nature of Science	**Fossils**	**Phylogeny**
▪ role of science fair ▪ focus on experimental design ▪ has done science fair but it has not gone well ▪ students only do experiments ▪ students required to do science fair ▪ used to teach scientific method in isolation but now integrates it with other science content ▪ scientists follow definite set of steps in performing the scientific method ▪ scientists use different methods depending on their question ▪ teacher cannot clarify how method is influenced by what is being studied ▪ teaches 3 different types of investigations	▪ does not cover why there are gaps in the fossil record ▪ fossil record provides evidence for evolution, but people interpret the evidence differently ▪ gaps caused by fossilization bias ▪ gaps caused by fossilization bias, but still provides evidence for evolution ▪ references transitional forms brought up during training ▪ there are unexplained gaps, but there is evidence there has been change through time ▪ used LTT resource to model fossilization bias ▪ stratigraphic layer modeling kit ▪ fossilization card game	▪ cladogram shows ▪ differentiates between monkey and ape ▪ great apes and monkeys continue to evolve ▪ humans and chimpanzees evolved from a common ancestor ▪ humans are related to monkeys, not descended from ▪ humans closest living relative is a chimpanzee ▪ presents from Creationist perspective that God gave humans and chimpanzees shared characteristics ▪ effect of training on understanding or approach to teaching ▪ calls groups *clades* ▪ references training activity to remember evidence in based on genetics and morphology ▪ training reinforced teacher belief that man was given dominion over animals ▪ use and/or reference training activities ▪ use training activity comparing humans and chimpanzees with students ▪ evidence for cladogram is based on/supported by ▪ genetic evidence ▪ morphology

Table 11

Summary of Participants' Posttraining Macroevolution PCK Themes According to Coding Construct, Continued

Coding Constructs for Pedagogical Content Knowledge about Macroevolution: Posttraining	
Deep Time	**Speciation**

▪ does not cover topic in depth because TEKS do not require it
▪ use activity from training
  ▪ activity based on training timeline or poster
  ▪ activity based on stratigraphic layer models
▪ use non-training activity
  ▪ compare timeline of student's life to all events in the past
  ▪ create a timeline of their life
  ▪ use timeline analogy
	▪ effect of training on understanding or approach to teaching
	  ▪ could/will use activity from curriculum guide
	  ▪ could/will use speciation lab from training activity
	▪ emphasis in activity based on training is resource is on
	  ▪ differential survival based on limited resources
	  ▪ geographical isolation
	  ▪ how different food or environment shapes adaptations
	  ▪ natural selection
	▪ use non-training activity to emphasize
	  ▪ form and function
	  ▪ geographic isolation

Chapter Four: Results

The results are presented below according to each of the study's research questions.

Research Question 1 – What is the effect of participating in a sustained professional development program on the 4th-8th grade teachers' understanding of macroevolution, particularly deep time, phylogenetics, speciation, fossils, and the nature of science?

Table 12 presents the mean test scores and standard deviations for all participants on the three different administrations of the MUM. As can be seen in Table 13, a repeated-measures ANOVA indicated that participants' understanding of macroevolution differed significantly between time points, $F\ (2,34) = 17.88$, $p < .001$, $\eta_p^2 = .51$. Using Cohen's (1988) conventions, this interaction was strong, as 51% of the within-subject variation was due to the interaction. Post hoc tests using the Bonferroni correction, presented in Table 14, revealed that attending the professional development series elicited a significant increase in teachers' understanding of macroevolution from the pretest to the posttest ($p=.001$), with the 95% confidence interval indicating that participants scored, on average, about 6 to 19 points higher on the posttest than the pretest. Additionally, participants scored significantly higher on the posttest than the midpoint ($p<.001$), with the 95% confidence interval indicating that participants scored, on average, 7 to 20 points higher on the posttest than the midpoint. The comparison of pretest to midpoint test scores was not significant ($p = 1$). Therefore, the results suggest that participating in the *Life Through Time* professional development program significantly increased teachers' understanding of macroevolution, but only after teachers participated in the entire professional development series.

Table 12

Means and Standard Deviations of Participants' MUM Scores at Three Time Points

	Mean	SD
MUM, Version 1: Pretest	78.4%	11.59
MUM, Version 2: Midpoint	76.9%	12.16
MUM, Version 3: Posttest	90.7%	6.26

Table 13

ANOVA Summary Table of Participants' MUM Scores at Three Time Points

Source	*SS*	*df*	*MS*	*F*
Test	2067.27	2	1033.63	17.88*
Error(test)	1965.66	34	57.81	-
Total	4032.93	36	1091.44	-

*$p < 0.001$

Table 14

Bonferroni Comparison of MUM Scores at Three Time Points

Comparisons	Mean Score Difference (%)	SE	95% CI Lower Bound	95% CI Upper Bound
Pretest vs. Midpoint	-1.44	2.63	-8.423	5.542
Midpoint vs. Posttest	13.79**	2.39	7.44	20.14
Pretest vs. Posttest	12.35*	2.58	5.51	19.18

* p = .001, ** p < .001

Research Question 2 – What is the effect of participating in a sustained professional development program on the 4th through 8th grade teachers' acceptance of evolution?

Table 15 presents the mean test scores and standard deviations for all participants on each administration of the MATE. As can be seen in Table 16, a repeated-measures ANOVA indicated that participants' acceptance of macroevolution differed significantly between time points, $F(2, 34) = 8.72$, $p = .001$, $\eta_p^2 = .34$. Using Cohen's (1988) conventions, this effect was strong, as 34% of the within-subject variation was due to the interaction. Post hoc tests using the Bonferroni correction, presented in Table 17, revealed that attending the professional development series elicited a significant increase in teachers' acceptance of macroevolution from the pretest to the posttest ($p=.003$). There was no significant difference between pretest to midpoint test scores ($p = .13$), or between midpoint to posttest scores ($p = .14$). Therefore, the results suggest that participating in the *Life Through Time* professional development program significantly increased teachers' acceptance of macroevolution, but only after teachers participated in the entire professional development series.

Table 15

Means and Standard Deviations of Participants' MATE Scores

	Mean	SD
MATE, Version 1: Pretest	78.1%	23.47
MATE, Version 2: Midpoint	84.5%	15.34
MATE, Version 3: Posttest	88.5%	12.21

Table 16

ANOVA Summary Table of Participants' MATE Scores at Three Time Points

Source	*SS*	*df*	*MS*	*F*
Test	4.12	2	2.01	8.72*
Error(test)	7.83	34	.23	-
Total	11.95	36	2.24	-

*p = 0.001

Table 17

Bonferroni Comparison of MATE Scores at Three Time Points

Comparisons	Mean Score Difference (%)	SE	95% CI Lower Bound	95% CI Upper Bound
Pretest vs. Midpoint	6.4	3	-1.56	14.36
Midpoint vs. Posttest	4.08	1.86	-.87	9.02
Pretest vs. Posttest	10.48*	3.46	1.28	19.67

* p = .003

Research Question 3 - What's the relationship between 4th through 8th grade teachers' understanding of macroevolution and their acceptance of evolution?

A series of Spearman rank-order correlations were conducted in order to determine if there were any relationships between teachers' understanding of macroevolution and acceptance of evolution on the MUM and MATE pretests, midpoint tests, and posttests respectively. In the non-parametric Spearman rank-order correlation, each variable is converted to a rank. After both variables are converted to ranks, the correlation analysis is conducted on the ranks (Myers & Well, 2003). A two-tailed test of significance indicated there was a significant positive correlation between participants' understanding of macroevolution and acceptance of evolution on the pretest assessments, $r(18) = .53$, $p = .03$, as well as on the posttest assessments, $r(18) = .75$, $p < .001$. Using Cohen's (1988) conventions, there's a substantial linear association between understanding of macroevolution and acceptance of evolution on the pretests and posttest.

A similar two-tailed test of significance indicated understanding of evolution and acceptance of macroevolution were marginally significant on the midpoint tests, $r(18) = .43$, $p = .08$. Thus, there's a moderate to substantial linear relationship between understanding of macroevolution and acceptance of evolution on the midpoint tests (Cohen, 1988). The results suggest that participants who have an increased understanding of macroevolution tend to be more likely to accept evolution.

Research Question 4 - How is 4th through 8th grade teachers' understanding of macroevolution related across three time points?

Table 18 presents the descriptive statistics for the simple linear regression of the pretest MUM scores toward scores on the midpoint MUM. Table 19 presents the results of the simple linear regression. The results indicate a moderate, positive relationship between participants' pretest MUM scores and their midpoint MUM scores ($\beta = .56$, $t(16) = 2.7$, $p = .02$). Approximately 31% of the variability in participants' scores on the midpoint MUM can be explained by the pretest MUM scores ($R^2 = .31$, $F(1,16) = 7.27$, $p = .02$).

Table 18

Descriptive Statistics for Pretest and Midpoint MUM Scores

	Pretest MUM scores	Midpoint MUM scores
Mean (%)	78.4	77
Standard Deviation	11.58	12.16

Table 19

Linear Regression Analysis of Participants' Midpoint MUM Scores by Pretest MUM Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MUM Scores	.59	.22	.56	2.7	.02

NOTE: R^2 = .31, F(1, 16) = 7.27, p = .02

Table 20 presents the descriptive statistics for the simple linear regression of the midpoint MUM scores toward scores on the posttest MUM. The results of the simple linear regression are presented in Table 21. The results of the regression revealed a moderate, positive relationship between participants' midpoint MUM scores and their posttest MUM scores (β = .55, t(16) = 2.65, p = .02). Approximately 30% of the variability in participants' scores on the posttest MUM are attributable to differences in the midpoint MUM scores (R^2 = .30, F(1,16) = 7, p = .02).

Table 20

Descriptive Statistics for Midpoint and Posttest MUM Scores

	Midpoint MUM scores	Posttest MUM scores
Mean (%)	77	90.8
Standard Deviation	12.16	6.25

Table 21

Linear Regression Analysis of Participants' Posttest MUM Scores by Midpoint MUM Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MUM Scores	.84	.11	.55	2.65	.02

NOTE: R^2 = .30, F(1, 16) = 7, p = .02

Table 22 presents the correlation matrix and descriptive statistics for the multiple regression of the pretest and midpoint MUM scores toward scores on the posttest MUM. Note that the all correlations are positive. Thus, as both pretest and midpoint scores increase, respondents are more likely to have an increased score on the posttest MUM. The results of the multiple linear regression suggest that a marginally significant proportion of the posttest MUM scores were predicted by the pretest and midpoint MUM scores (R^2 = .31, F(1, 16) = 3.37, p = .06). As can be seen in table 23, the midpoint MUM scores had marginally significant positive regression weights, indicating participants with higher scores on the midpoint MUM were expected to have higher posttest MUM scores, after controlling for the other variables in the model (β = .5, t(2, 15) = 1.93, p = .07). Pretest MUM scores did not contribute to the model. Because of the small sample size of the study, more data points are needed to fully support the results of the multiple regression analysis regression.

Table 22

Correlation Matrix and Descriptive Statistics for Pretest and Midpoint MUM Scores Towards Posttest MUM Scores

	1	2	3
Posttest MUM Score	1	-	-
Midpoint MUM Score	.55**	1	-
Pretest MUM Score	.37*	.56**	1
Mean (%)	90.8	77	78.4
Standard Deviation	6.25	12.16	11.57

NOTE: Posttest MUM score is the dependent variable. **p = .06, *p < .01

Table 23

Multiple Regression Analysis of Participants' Posttest MUM Scores by Pretest and Midpoint MUM Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MUM Scores	.05	.14	.09	.36	.72
Midpoint MUM Scores	.26	.13	.5	1.93	.07

NOTE: R^2 = .31, F(2, 15) = 3.37, p = .06

Summary findings for research question 4. As can be seen in Figure 3, the results of the simple linear regression show participants' pretest scores on the MUM significantly predict scores on the midpoint MUM, and scores on the midpoint MUM significantly predict scores on the posttest MUM. The results of the multiple regression indicate that although a marginally significant portion of the posttest MUM scores were predicted by the pretest and midpoint MUM scores, it is the midpoint MUM scores that played a major role in predicting the posttest MUM scores (β = .5, t(2, 15) = 1.93, p = .07).

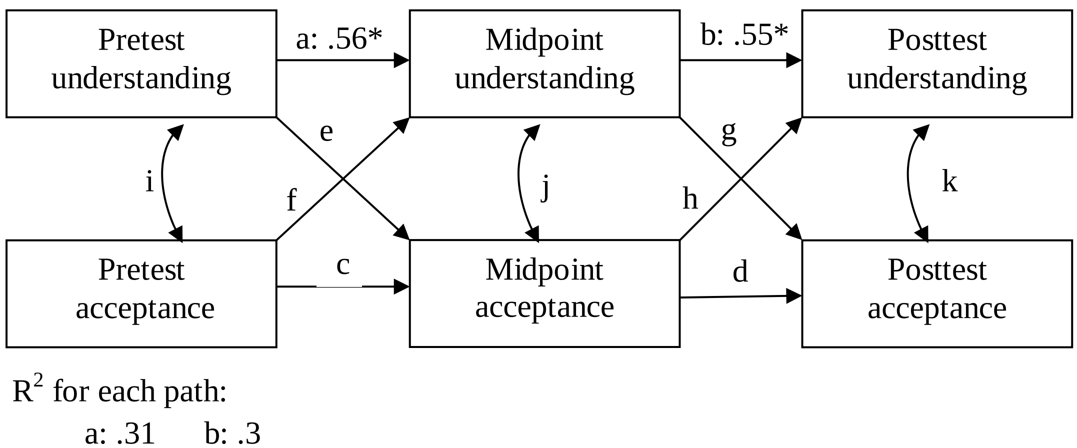


Figure 3. Regression model: Influence of pretest MUM scores on midpoint MUM scores, and midpoint MUM scores on posttest MUM scores. * $p \leq .05$

Research Question 5 - How is 4th through 8th grade teachers' acceptance of evolutionary theory related across three time points?

Table 24 presents the descriptive statistics for the simple linear regression of the pretest MATE scores toward scores on the midpoint MATE. Table 25 presents the results of the simple linear regression. The results indicate a strong, positive relationship between participants' pretest MATE scores and their midpoint MATE scores (β = .84, t(16) = 6.23p < .01). Almost 70% of the variability in participants' scores on the midpoint MATE can be explained by the pretest MATE scores (R^2 = .69, F(1,16) = 38.76, p < .01).

Table 24

Descriptive Statistics for Pretest MATE and Midpoint MATE Scores

	Pretest MATE scores	Midpoint MATE scores
Mean (%)	78.1	84.5
Standard Deviation	23.47	15.34

Table 25

Linear Regression Analysis of Participants' Midpoint MATE Scores by Pretest MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MATE Scores	.95	.15	.84	6.23	<.001

NOTE: R^2 = .69, F(1, 16) = 38.76, p < .001

Table 26 presents the descriptive statistics for the simple linear regression of the midpoint MATE scores toward scores on the posttest MUM. The results of the simple linear regression are presented in Table 27. The results of the regression revealed a strong, positive relationship between participants' midpoint MATE scores and their posttest MATE scores (β = .89, t(16) = 7.87 p < .001). Approximately 80% of the variability in participants' scores on the posttest MATE are attributable to differences in the midpoint MATE scores (R^2 = .8, F(1,16) = 61.91, p < .001).

Table 26

Descriptive Statistics for Midpoint MATE and Posttest MATE Scores

	Midpoint MATE scores	Posttest MATE scores
Mean (%)	84.5	88.5
Standard Deviation	15.34	12.21

Table 27

Linear Regression Analysis of Participants' Posttest MATE Scores by Midpoint MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MATE Scores	.88	.11	.89	7.87	<.001

NOTE: R^2 = .8, F(1, 16) = 61.91, p < .001

Table 28 presents the correlation matrix and descriptive statistics for the multiple regression of the pretest and midpoint MATE scores toward scores on the posttest MATE. Note that all of the correlations are positive and significant. Thus, as both pretest and midpoint scores increase, respondents are more likely to have an increased score on the posttest MATE. The results of the multiple linear regression indicate that a significant proportion of the posttest MATE scores were predicted by the pretest and midpoint MATE scores (R^2 = .82, F(1, 16) = 33.68, p < .001). As can be seen in Table 29, the midpoint MATE scores had significant positive regression weights, indicating participants with higher scores on the midpoint MATE were expected to have higher posttest MATE scores, after controlling for the other variables in the model (β = .64, t(2, 15) = 3.21, p = .006) . Pretest MATE scores did not contribute significantly to the model.

Table 28

Correlation Matrix and Descriptive Statistics for Pretest and Midpoint MATE Scores Towards Posttest MATE Scores

	1	2	3
Posttest MATE Score	1	-	-
Midpoint MATE Score	.89*	1	-
Pretest MATE Score	.83*	.84*	1
Mean (%)	88.5	84.5	78.1
Standard Deviation	12.31	15.34	23.47

NOTE: Posttest MATE score is the dependent variable. *p <.001

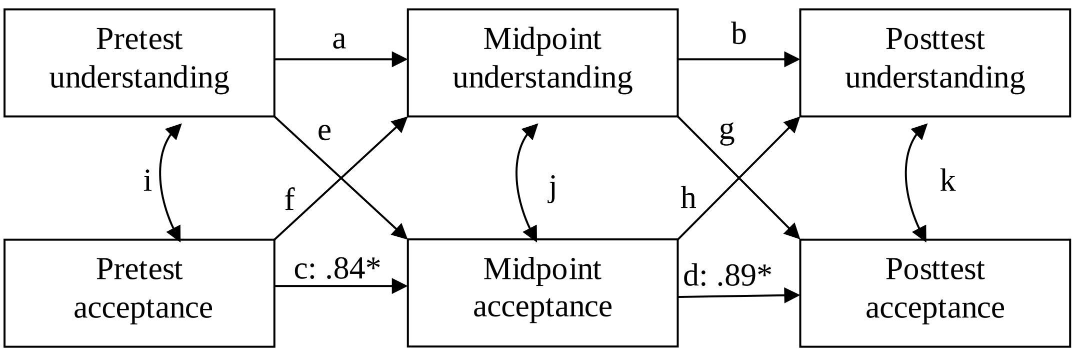
Table 29

Multiple Regression Analysis of Participants' Posttest MATE Scores by Pretest and Midpoint MATE Scores

Independent Variable	B	SE_b	β	t	p
Pretest MATE Scores	.31	.23	.28	1.38	.19
Midpoint MATE Scores	.64	.2	.65	3.21	.006

NOTE: R^2 = .82, F(2, 15) = 33.68, p < .001

Summary findings for research question 5. In summary, as can be seen in Figure 4, the results of the simple linear regression show participants' pretest scores on the MATE significantly predict scores on the midpoint MATE, and scores on the midpoint MATE significantly predict scores on the posttest MATE. The results of the multiple regression of pretest and midpoint MATE scores on posttest MATE scores indicate that the midpoint MATE scores play a significant role in predicting the posttest MATE scores ($\beta = .64$, $t(2, 15) = 3.21$, $p = .006$).



R^2 for each path:

c: .69 d: .8

Figure 4. Regression model: Influence of pretest MATE scores on midpoint MATE scores, and midpoint MATE scores on posttest MATE scores. * $p \leq .05$

Research Question 6 - What is the effect of understanding of macroevolution on acceptance of evolutionary theory and the effect of acceptance of evolutionary theory on understanding of macroevolution across time?

Table 30 presents the descriptive statistics for the simple linear regression of the pretest MATE scores toward scores on the midpoint MUM. The results of the simple linear regression are presented in Table 31. The results of the regression revealed a nonsignificant proportion of the total variation in midpoint MUM scores was predicted by participants' pretest MATE scores (R^2 = .08, F(1, 16) = 1.33, p = .27).

Table 30

Descriptive Statistics for Pretest MATE and Midpoint MUM Scores

	Pretest MATE scores	Midpoint MUM scores
Mean (%)	78.1	77
Standard Deviation	23.47	12.16

Table 31

Linear Regression Analysis of Participants' Midpoint MUM Scores by Pretest MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MATE Scores	2.91	.2.52	.28	1.15	.27

NOTE: R^2 = .08, F(1, 16) = 1.33, p = .27

Table 32 presents the descriptive statistics for the simple linear regression of the pretest MUM scores toward scores on the midpoint MATE. The results of the simple linear regression are presented in Table 33. The results of the regression revealed a significant, positive relationship between participants' pretest MUM scores and their midpoint MATE scores (β = .48, t(16) = 1.15, p =.05). Approximately 23% of the variability in participants' scores on the midpoint MATE are attributable to differences in the pretest MUM scores (R^2 = .23, F(1,16) = 4.67, p =.05).

Table 32

Descriptive Statistics for Pretest MUM and Midpoint MATE Scores

	Pretest MUM scores	Midpoint MATE scores
Mean (%)	78.4	84.5
Standard Deviation	11.58	15.34

Table 33

Linear Regression Analysis of Participants' Midpoint MATE Scores by Pretest MUM Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MUM Scores	.05	.03	.48	2.16	.05

NOTE: R^2 = .23, F(1, 16) = 4.67, p = .05

Table 34 presents the descriptive statistics for the simple linear regression of the midpoint MATE scores toward scores on the posttest MUM. The results of the simple linear regression are presented in Table 35. The results of the regression revealed a significant proportion of the total variation in posttest MUM scores was predicted by participants' midpoint MATE scores (β = .7, t(16) = 3.91, p = .001). Almost 50% of the variability in participants' scores on the posttest MUM is attributable to differences in the midpoint MATE (R^2 = .49, F(1, 16) = 15.26, p = .001).

Table 34

Descriptive Statistics for Midpoint MATE and Posttest MUM Scores

	Midpoint MATE scores	Posttest MUM scores
Mean (%)	84.5	90.8
Standard Deviation	15.34	6.25

Table 35

Linear Regression Analysis of Participants' Posttest MUM Scores by Midpoint MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MATE Scores	3.34	.86	.7	3.9	.001

NOTE: R^2 = .49, F(1, 16) = 15.26, p = .001

Table 36 presents the descriptive statistics for the simple linear regression of the midpoint MUM scores toward scores on the posttest MATE. The results of the simple linear regression are presented in Table 37. The results of the regression revealed a marginally significant proportion of the total variation in posttest MATE scores was predicted by participants' midpoint MUM scores (β = .44, t(16) = 2, p = .07). Approximately 20% of the variability in participants' scores on the posttest MATE are attributable to differences in the midpoint MUM (R^2 = .2, F(1, 16) = 3.91, p = .07).

Table 36

Descriptive Statistics for Midpoint MUM and Posttest MATE Scores

	Midpoint MUM scores	Posttest MATE scores
Mean (%)	77	88.5
Standard Deviation	12.16	12.21

Table 37

Linear Regression Analysis of Participants' Posttest MATE Scores by Midpoint MUM Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MATE Scores	.05	.02	.44	2	.07

NOTE: R^2 = .2, F(1, 16) = 3.91, p = .07

Table 38 presents the correlation matrix and descriptive statistics for the multiple regression of the pretest MATE and pretest MUM scores toward scores on the posttest MUM. Note that all of the correlations are positive, and at least marginally significant. Thus, as both pretest scores on both the MATE and MUM increase, respondents are more likely to have an increased score on the posttest MUM. The results of the multiple linear regression suggest that a significant proportion of the posttest MUM scores were predicted by the pretest MUM and MATE scores (R^2 = .36, F(2, 15) = 4.26, p = .03). As can be seen in Table 39, the pretest MATE scores had significant positive regression weights, indicating participants with higher scores on the pretest MATE were expected to have higher posttest MUM scores, after controlling for the other variables in the model. Pretest MUM scores did not contribute significantly to the model.

Table 38

Correlation Matrix and Descriptive Statistics for Pretest MATE and Pretest MUM Scores Towards Posttest MUM Scores

	1	2	3
Posttest MUM Score	1	-	-
Pretest MATE Score	.6**	1	-
Pretest MUM Score	.37*	.61**	1
Mean (%)	90.8	78.1	78.4
Standard Deviation	6.25	23.47	11.57

NOTE: Posttest MUM score is the dependent variable. *p = .06, **p = .004

Table 39

Multiple Regression Analysis of Participants' Posttest MUM Scores by Pretest MUM and MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MUM Scores	.01	.14	.01	.03	.98
Pretest MATE Scores	3.23	1.41	.6	2.3	.04

NOTE: R^2 = .36, F(2, 15) = 4.26, p = .03

Table 40 presents the correlation matrix and descriptive statistics for the multiple regression of the pretest MATE and pretest MUM scores toward scores on the posttest MATE. Note that all of the correlations are positive and significant. Thus, as both pretest scores on both the MATE and MUM increase, respondents are more likely to have an increased score on the posttest MATE. The results of the multiple linear regression suggest that a significant proportion of the posttest MATE scores were predicted by the pretest MUM and MATE scores ($R^2 = .73$, $F(2, 15) = 17.01$, $p < .001$). As can be seen in Table 41, the pretest MATE scores had significant positive regression weights, indicating participants with higher scores on the pretest MATE were expected to have higher posttest MATE scores, after controlling for the other variables in the model. Pretest MUM scores did not contribute significantly to the model.

Table 40

Correlation Matrix and Descriptive Statistics for Pretest MATE and Pretest MUM Scores Towards Posttest MUM Scores

	1	2	3
Posttest MATE Score	1	-	-
Pretest MATE Score	.83*	1	-
Pretest MUM Score	.54***	.61**	1
Mean (%)	88.5	78.1	78.4
Standard Deviation	12.21	23.47	11.57

NOTE: Posttest MATE score is the dependent variable. *p = .01, **p = .004, ***p < .001

Table 41

Multiple Regression Analysis of Participants' Posttest MATE Scores by Pretest MUM and MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Pretest MUM Scores	.01	.02	.04	.24	.82
Pretest MATE Scores	.9	.2	.81	4.47	<.001

NOTE: $R^2 = .73$, $F(2, 15) = 17.01$, $p < .001$

Table 42 presents the correlation matrix and descriptive statistics for the multiple regression of the midpoint MATE and midpoint MUM scores toward scores on the posttest MUM. Note that all of the correlations are positive and significant. Thus, as both midpoint scores on both the MATE and MUM increase, respondents are more likely to have an increased score on the posttest MUM. The results of the multiple linear regression suggest that a significant proportion of the posttest MUM scores were predicted by the pretest MUM and MATE scores ($R^2 = .55$, $F(2, 15) = 9.17$, $p = .003$). As can be seen in Table 43, the midpoint MATE scores had significant positive regression weights, indicating participants with higher scores on the midpoint MATE were expected to have higher posttest MUM scores, after controlling for the other variables in the model. Midpoint MUM scores did not contribute significantly to the model.

Table 42

Correlation Matrix and Descriptive Statistics for Midpoint MATE and Midpoint MUM Scores Towards Posttest MUM Scores

	1	2	3
Posttest MUM Score	1	-	-
Midpoint MATE Score	.7**	1	-
Midpoint MUM Score	.55***	.48*	1
Mean (%)	90.8	84.5	77
Standard Deviation	6.25	15.34	12.16

NOTE: Posttest MUM score is the dependent variable. *p = .02, **p = .001, ***p = .009

Table 43

Multiple Regression Analysis of Participants' Posttest MUM Scores by Midpoint MUM and MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MUM Scores	.15	.1	.28	1.44	.17
Midpoint MATE Scores	2.7	.94	.56	2.86	.01

NOTE: R^2 = .55, F(2, 15) = 9.17, p = .003

Table 44 presents the correlation matrix and descriptive statistics for the multiple regression of the midpoint MATE and midpoint MUM scores toward scores on the posttest MATE. Note that all of the correlations are positive and significant. Thus, as both midpoint scores on both the MATE and MUM increase, respondents are more likely to have an increased score on the posttest MATE. The results of the multiple linear regression indicate that a significant proportion of the posttest MATE scores were predicted by the midpoint MUM and MATE scores ($R^2 = .8$, $F(2, 15) = 29.09$, $p < .001$). As can be seen in Table 45 the midpoint MATE scores had significant positive regression weights, indicating participants with higher scores on the midpoint MATE were expected to have higher posttest MATE scores, after controlling for the other variables in the model. Midpoint MUM scores did not contribute significantly to the model.

Table 44

Correlation Matrix and Descriptive Statistics for Midpoint MATE and Midpoint MUM Scores Towards Posttest MATE Scores

	1	2	3
Posttest MATE Score	1	-	-
Midpoint MATE Score	.89***	1	-
Midpoint MUM Score	.44*	.48**	1
Mean (%)	88.5	84.5	77
Standard Deviation	12.21	15.34	12.16

NOTE: Posttest MATE score is the dependent variable. *p = .03, *p = .02, ***p < .001

Table 45

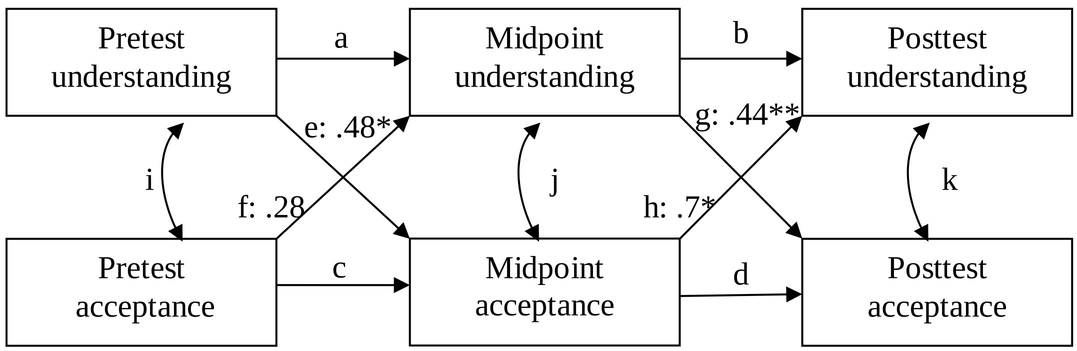
Multiple Regression Analysis of Participants' Posttest MATE Scores by Midpoint MUM and MATE Scores

Independent Variable	*B*	SE_b	β	*t*	*p*
Midpoint MUM Scores	.002	.01	.02	0.18	.86
Midpoint MATE Scores	.87	.13	.88	6.62	<.001

NOTE: $R^2 = .8$, $F(2, 15) = 29.09$, $p < .001$

Summary findings for research question 6. As can be seen in Figure 5, the results of the simple regression indicate that participants' pretest scores on the MUM significantly predict scores on the midpoint MATE, and scores on the midpoint MUM were marginally significant in predicting scores on the posttest MATE. Thus, the results suggest that as understanding of macroevolution evolution increases, participants are more favorably disposed towards accepting evolution. Participants' scores on the pretest MATE were not significant predictors for participants' scores on the midpoint MUM; however, participants' scores on the midpoint MATE were significant predictors to their scores on the posttest MUM. The results suggest that as participants partake in more of the training sessions and have an increased acceptance of evolution, they are more likely to understand macroevolution.

The pretest MATE scores played a significant role in predicting the dependent variable in the multiple regressions of: 1. the pretest MATE and MUM scores on posttest MUM scores, and 2. the pretest MATE and MUM scores on posttest MATE scores. The pretest MUM scores were not significant predictors in either regression model. The midpoint MATE scores played a significant role in predicting the dependent variable in the multiple regressions of: 1. the midpoint MATE and MUM scores on posttest MUM scores, and 2. midpoint MATE and MUM scores on posttest MATE scores. The midpoint MUM scores were not significant in either regression model. The results of the multiple regression analysis suggest that as acceptance of evolution increases, participants are more favorably disposed towards both understanding and accepting evolution.



R^2 for each path:

e: .23 f: .08 g: .2 h: .49

Figure 5. Regression model: Influence of understanding of macroevolution on acceptance of evolution and the influence of acceptance of evolution on understanding of macroevolution. * p ≤ .05, **p = .07

Research Question 7 - What is the effect of the professional development series on teachers' with varying levels of acceptance of evolutionary theory approach to teaching evolution in schools, awareness of challenges to teaching evolution, and pedagogical content knowledge about teaching macroevolution?

Teachers' acceptance of evolutionary theory influences their instructional approach taken toward teaching evolution (Deniz et al., 2008; Nadelson, 2009; Rutledge and Mitchell, 2002). The results of this research question are presented in terms of a cross-acceptance group and within-acceptance group analysis of how teachers described their: 1. approach to teaching evolution, including how they decide which evolution concepts to teach, which evolution concepts they taught, and how they presented those concepts; 2. awareness of challenges to teaching evolution, including their response to a student questioning if they believe in evolution, the main challenges they have in teaching evolution, and their response to concerns about how evolution is presented in their class; and 3. pedagogical content knowledge about teaching macroevolution, particularly the nature of science, speciation, deep time, fossils, and phylogeny. Demographic information about the eight interview participants is presented first, followed by the results.

Interviewee demographics. The interview participants included eight teachers with varying levels of acceptance of evolution, teaching experience, and background knowledge of science. Participants are referred to by pseudonyms. Table 46 includes the interviewees' initial acceptance group classification, based on their initial MATE score, and the pretest and posttest scores on the MATE and MUM. Table 47 presents personal interviewee data, including years teaching experience, school demographics, and college science preparation.

Table 46

Interviewee Initial Evolution Acceptance Level Classification, and Pretest and Posttest MATE and MUM scores

Acceptance Group Classification	Teacher Name (Pseudonym)	Initial Acceptance Level (Pretest MATE)	Final Acceptance Level (Posttest MATE)	Pretest MUM Score (%)	Posttest MUM Score (%)	% Change in Pre- to Posttest MUM Score
Very High	Annie	Very High	Very High	100	96	-4
Very High	Stan	Very High	Very High	96	100	4
Very High	Tammy	Very High	Very High	89	100	11
Moderate	Sonja	High	Very High	85	93	8
Moderate	Tara	Moderate	Very High	67	96	29
Low	Julianne	Low	High	67	82	15
Low	Teresa	Very Low	Low	67	89	22
Low	Joycelyn	Very Low	High	78	82	4

Table 47

Interviewee Demographics

Teacher Name (Pseudonym)	Yrs Teaching Experience	Grade Level(s) Teaching	School Type	Teaching Certification Type	Undergraduate or Graduate Degree(s) in Science Field?	Average # hours - science college coursework
Annie	6	middle school	public	Science 4th-8th & 8th-12th	Yes	97
Stan	14	middle school	public	Science Composite 6th-12th; Biology 6th-12th	Yes	72
Tammy	14	elementary school	public	Elementary 1st-8th	Yes	40
Sonja	20	elementary school	public	Bilingual Generalist Early Childhood-8th	No	12
Tara	1	middle school	public	Science 4th-8th	No	19
Julianne	10	elementary school	public	Elementary 1st-8th; & Science 4th-8th	No	23
Teresa	4	elementary & middle school	private	Elementary 1st-8th; Elementary Biology 1st-8th	No	24
Joycelyn	9	elementary school	public	Elementary 1st-8th; Science 4th-8th	No	24

Participants' pseudonyms, professional preparation, school characteristics, and brief narratives follow.

Very high acceptance group interviewees.

Annie. Annie is a seventh year teacher who teaches eighth grade science at an all girls' school in an urban school district in Central Texas. Annie entered the study as a very high acceptor of evolution, as measured by her MATE score, and remained a very high acceptor throughout the study. However, Annie has not always been accepting of evolution. While growing up, she frequently attended a Christian church and believed in a literal interpretation of the Bible's six day creation story. She recalls learning about evolution in high school:

> Honestly I know what it's like being the person who doesn't believe because that's how I grew up. I remember sitting in my 9th grade biology class learning about this. Like my nervous system would start to freak out and I would get hot and I would be like 'No, this isn't true'. This isn't true and I would get so upset (pre-interview).

Upon entering college and taking more biology classes, she decided the "whole six days of creation story couldn't possibly be true" (pre-interview). It was during her college coursework in biology that she chose to accept evolutionary theory, and reject creationism.

Annie has a strong understanding of macroevolution, as measured by her perfect score of 100 percent on the initial MUM and her score of 96 on the final MUM. She feels well equipped to teach evolution, particularly primate evolution, because of her own personal college education. Annie finds evolution to be one of the most fascinating subjects of her entire adult life. She often brings up the topic in her classroom, even though she might not do a specific lesson about evolution.

Though Annie feels confident in her life science content knowledge, she wanted to attend the *Life Through Time* series to learn more about the earth science components related to evolution, and hands-on activities to teach those concepts. She also wanted to learn more "real-world, authentic projects" focusing on an integrated approach to teaching science (application).

Stan. Stan has 14 years teaching experience, and teaches 6th grade science and integrated physics and chemistry at an urban charter school in Central Texas. Stan began the study as a very high acceptor of evolution, and remained very highly accepting throughout the study. He reports being a strong supporter of evolution, and works to add evolution-themed concepts into his curriculum when the concepts align with the TEKS.

Stan is frustrated with the political resistance to teaching evolution in Texas. He perceives that the government is "trying to water down the TEKS" and repeatedly asks what he can do to change the science standards to incorporate more evolution concepts (pre-interview). Though he says other schools' administrators are afraid for their teachers to even say the word evolution, his administration does not restrict his ability to incorporate evolution into his classroom, which gives him "more confidence and power in teaching it" (pre-interview).

Stan has a strong grasp of macroevolution, as reflected in his score of 96 percent in the MUM pretest and 100 percent on the posttest. He emphasizes the nature of science throughout his science curriculum, and has extensive prior knowledge about the challenges to teaching evolution. Prior to attending the training series, he already incorporated several activities and discussions into his curriculum which directly address the alternate conceptions students hold about evolution and the nature of science.

Stan wanted to attend the training to learn how to integrate community resources and more project-based instruction into his classroom curriculum. He also wanted to attend to further explore how to integrate life and earth sciences in his teaching.

Tammy. Tammy has 14 years teaching experience, and teaches 5th grade at a public suburban school in Central Texas. She attended college in Canada where she earned a Bachelor of Arts in Anthropology and a Bachelor of Education in Education. Tammy feels prepared to teach evolution because of her college preparation.

Though Tammy is a very high acceptor of evolution and has a firm understanding of macroevolutionary concepts, she questions if she is actually supposed to teach evolution in Texas because she views that evolution is perceived to be a controversial topic by Texans. When she taught in Canada, religion and science were taught as separate subjects and she did not encounter resistance to the teaching of evolution. On the contrary, she frequently hears the students say, "God did everything," when she discusses evolution with her Texas students (pre-interview). She also feels her colleagues resist teaching of evolution because of their Christian fundamentalist views.

Tammy wanted to attend the training so she could learn how to make concepts related to life through time accessible to "a cultural group who has traditionally not seen this area of study to be relevant to their lives" (application). She recognized that change through time is hard for students to understand, especially those who have little experience outside the classroom, and wanted to enrich her curriculum to help her teach it more effectively. She also sought to learn how the State of Texas wants her to address evolution in her class, and the specific TEKS she should cover in discussing evolutionary concepts. Furthermore, she was interested in collaborating with scientists and teachers alike to share resources about the teaching of life through time.

Moderate acceptance group interviewees.

Sonja. Sonja has more than 20 years of experience teaching first grade through adult education. When the study began, she was a self-contained, bilingual 4th grade teacher at a public, suburban school in Central Texas. Sonja admits that, because of testing pressure, science has a limited role in her class. She explains, "First we were about the writing test and then we were about the reading test and the math test and then whatever we don't cover in science just gets thrown in last" (pre-interview). At her principal's request, Sonja attended multiple science professional development programs to improve her science teaching. However during the study at the beginning of the 2011-

2012 school year, she was reassigned to teach only language arts to 4th and 5th grades because the principal was still dissatisfied with her science teaching.

With 12 hours, she took the least amount of science coursework in college of all study participants. She recognizes that she has a very limited science background and explains,

> I don't have a very good background in science because what I was, was a secondary ESL teacher and I switched to bilingual. And to be brutally honest it's because bilingual teachers get a stipend…In this state you just take a test and if you can pass it, you can teach whatever that was, whether you are really qualified or not. That was one of the reasons I wanted this training is because my background in science is pretty limited (pre-interview).

Though Sonja had little college coursework in science her initial score on the MUM of 85 percent demonstrates that she had a relatively firm understanding of macroevolution, even upon entering the study. She gained 8 percentage points on the posttest MUM, and scored 93 percent. Sonja was highly accepting of evolution upon entering the program, and very highly accepting upon completion of the training.

Sonja wanted to attend the training to help increase her science content knowledge. She recognized that earth science is a particularly challenging area for her students, and that her bilingual students have a difficult time transferring hands-on activities to learning the concepts behind the activities. Thus, she wanted to attend to strengthen her teaching of earth science, and learn how to improve student knowledge transfer.

Tara. Tara is in her second year of teaching 8th grade science at a public urban school in Central Texas. Upon entering the study, Tara was moderately accepting of evolution. At the end of the study, she scored at the very high acceptance level on the MATE. Tara believes that religion and evolution can co-exist, though she does not think her students hold the same belief structure. She reports approaching teaching socially controversial topics, including evolution and climate change, by presenting concepts in a neutral light, in the hopes of keeping the students' minds open and not make them defensive about their religious beliefs.

Tara feels confident in her geology knowledge, and attributes that confidence to learning from her mother. Though Tara felt confident in her geology knowledge, she would often ask questions about introductory level geology material presented in class. She entered the training with a moderate understanding of macroevolution, as reflected on her score of 67 percent on the initial MUM. She understood considerably more about macroevolution at the end of the study, and scored a 96 on the posttest MUM.

Tara wanted to attend the training to learn "new and innovative ideas to allow for the highest return for students" (application). As a novice teacher, she is particularly interested in learning more ways to teach science, particularly ways to teach students that "bring out their willingness to learn" as many of her students do not think they need to learn science (application).

Low acceptance group interviewees.

Julianne. Julianne has 10 years elementary teaching experience. Upon entering the study, she taught 5th grade science, social studies, and language arts at a suburban school in Central Texas. However, midway through the study at the beginning of the 2011-2012 school year, Julianne was removed from teaching science by the school principal due to the low performance of her students on the science portion of the Texas Assessment of Knowledge and Skills, Texas' standardized science assessment. She was reassigned to teach 5th grade reading, spelling, and social studies.

When Julianne began the study, she was a low acceptor of evolution, and believed that God has a role in evolutionary processes. After participating in the study, Julianne's posttest score on the MATE reflected she was a high acceptor of evolution

Though Julianne held persistent alternate conceptions about the nature of science and macroevolution throughout the series, the professional development session did impact her understanding of macroevolution. She scored 82 percent on the posttest MUM, which is 15 percentage points higher than her score on the initial MUM of 67 percent.

Julianne wanted to attend the *Life Through Time* training to help improve her science teaching, particularly how to integrate earth and life sciences in her curriculum. She reported having a strong life science background, but wanted to improve her knowledge of geology. Her goal was to become a science specialist for a school district.

Teresa. Teresa has four years teaching experience, and teaches 5th through 8th grade science at a suburban private school in Central Texas. Though Teresa entered the study as a very low acceptor of evolution, the training did have an impact on her acceptance. Upon completion of the training programs she was more accepting and scored at the low acceptance level.

Teresa is a self-described creationist who believes in Intelligent Design in which God designed the natural world. She accepts certain aspects of concepts related to evolution, including microevolution and stratigraphic principles, but wholeheartedly rejects other concepts, particularly macroevolution and human evolution. She believes that some evolution concepts are “value judgments”, such as the evolution of the eye, and that there is both scientific and religious evidence to refute these “value judgments” (pre-interview).

Though she has a strong faith, she says she is open to learning perspectives other than her own. However, Teresa almost dropped out of the study after the first class day because the evolution content was in direct conflict with what she believed. She explained,

> I didn’t even think I’d make it through the first class. I thought I’m going to have to drop this. I can’t do this and by the end I was totally like I can do this. I understand. It’s okay where I’m coming from….Because I was so close. I went home crying, ‘I can’t do this.’ This is going to be too hard for my head. I don’t know if I can embrace this. My husband was like, ‘You need this. This is going to push you. Anytime you want to quit is when you always tell me to encourage you’ (post-interview).

Teresa felt confident in her subject matter knowledge because she took an evolution course in college. Though she was confident in her knowledge of evolution, she actually had a moderate understanding of macroevolution upon beginning the study, and scored a 67 percent on the pretest MUM. Upon exit, she increased her understanding substantially, and scored an 89 percent on the posttest MUM.

Teresa wanted to attend the training to increase her content knowledge, particularly about anatomy, and to further develop her knowledge and skills about teaching through an integrated life and earth science approach. Additionally, she previously attended trainings sponsored by the Texas Natural Science Center, and wanted to attend others because the previous ones had a positive impact on her content knowledge and pedagogical skills.

Joycelyn. Joycelyn teaches 5th grade science and language arts at an urban, public school in Central Texas. Joycelyn began the study as a very low acceptor of evolution, and would introduce creationist concepts into her teaching. By the end of the study, Joycelyn was a high acceptor of evolution.

In her posttraining interview she says that she “believes” in evolution and, despite the popular stereotype, that does not make her an atheist. Her husband was concerned that learning additional science concepts would cause her to reject religion. She explains,

> I’m even fighting with my husband at home over the same kind of thing. Well because I’ve been going through this [training] and he’s like, ‘I don’t know how

> much more science I really want you to learn because the next thing I know you're going to say that there's no [God]' (post-interview).

While she accepts evolution, she also "totally agrees with the Bible" because there are a lot of things humans cannot explain about the natural world without invoking a supernatural being.

While Joycelyn's acceptance of evolution greatly increased while participating in the study, her understanding of macroevolution remained relatively consistent. She had a firm understanding of macroevolution upon entering the study, and scored a 78 on the original MUM, and earned an 82 percent on the posttest MUM.

Joycelyn wanted to attend the training to develop her content knowledge. She recognized that some aspects of earth and life science are challenging for students to understand and wants to learn how to "catch holes in students' knowledge and fill the holes" (application). She also wanted to learn how to make science more personal for the students so they are more interested, engaged, participate more, and learn more. Her goal is to become a science coordinator for a school or school district.

Approach to teaching evolution. Teachers' descriptions of how they decided what evolution concepts to teach, which evolution concepts they taught, and how they presented those concepts provided insight into teachers perceptions of the role of evolution in their class, both before and after the training. A cross-acceptance group comparison of coding constructs consistent among each acceptance group for their approach to teaching evolution is presented first, followed by a within acceptance group comparison of coding constructs different among each acceptance group. Table 48 presents a comparison of the coding constructs consistent among the teachers in each acceptance group for their approach to teaching evolution, both before and after the training. Of particular note is that upon completion of the training, every interviewee reported they either already had or planned on incorporating materials and/or resources from the training series into their classroom curriculum.

Table 48

Comparing Coding Constructs Consistent Among Acceptance Groups for Approach to Teaching Evolution

	Deciding what to teach	**Evolution concepts taught**	**How presented evolution concepts**
Very High Acceptors			
Pre-instruction: consistent constructs	▪ based on the TEKS	▪ deep time	▪ differentiate between science and religion
Post-instruction: consistent constructs	▪ based on the TEKS ▪ collaborated with colleagues	▪ no applicable constructs	▪ differentiate between science and religion ▪ incorporated materials and/or resources from the training series
Moderate Acceptors			
Pre-instruction: consistent constructs	▪ used a scope and sequence	▪ deep time	▪ focus on standardized test preparation ▪ science is perceived to be a less important subject
Post-instruction: consistent constructs	▪ no applicable constructs	▪ no applicable constructs	▪ incorporated materials and/or resources from the training series ▪ integrated the subject areas and/or scientific disciplines
Low Acceptors			
Pre-instruction: consistent constructs	▪ based on the TEKS	▪ adaptation ▪ does not cover/avoids teaching portions of evolution topics	▪ incorporate creationism
Post-instruction: consistent constructs	▪ no applicable constructs	▪ no applicable constructs	▪ incorporated materials and/or resources from the training series

Approach to teaching coding constructs consistent among very high acceptors. Very high acceptors of evolution consistently used the TEKS to decide what evolution concepts they would teach, both before and after the training. After the training, they also reported deciding what to teach based on collaborating with their colleagues. As part of that collaborative process, Stan and Tammy shared materials and resources from the training series with their colleagues. Stan's colleagues were receptive to learning about the training program material, particularly the activities from the training on creating and interpreting cladograms and phylogenies. Tammy's colleagues were not as accepting of the project curriculum. After participating in a project activity on geological process lead by Tammy, her colleagues responded, "I don't see how this fits with the TEKS. I don't know if we can use it" (post-interview). Tammy felt the teachers did not respond positively because they are resistant to learning and incorporating any new ideas in their classroom.

Very high acceptors were the only group of teachers that consistently approached the teaching of evolution by specifically addressing the nature of science through differentiating between science and religion as separate ways of looking at the world. Tammy differentiates between the two in her teaching by explaining science is based on evidence, and religion is based on faith. Stan incorporates the nature of science extensively in his classroom, and begins the year by teaching about what science is and is not. He emphasizes that science is measurable, repeatable, reliable, and based on evidence, while religion is based on belief. Stan reports that his approach helps students who are reluctant to learning about evolution because they are less likely to feel that evolution is a personal attack on their beliefs. Annie elicits her students' conceptions about the relationship of evolution and religion by holding a class discussion concerning whether creationism should be taught in the science classroom. Through the course of the discussion, she reinforces that science is evidence-based and is subject to peer review, while religion is based on belief. Annie reports that her students say she does an effective job at differentiating between science and religion without pushing her beliefs on them.

After the training, all of the very high acceptors consistently approached the teaching of evolution by using, or planning on using, materials and resources from the training program into their classroom. They also reported using a broad range of activities with their students covering multiple aspects of macroevolution, including deep time, the nature of science, and phylogeny. Annie thought the introductory activity to the Tree of Life session in which participants were given photos of extant and extinct organisms and were asked to classify them according to any schema they wanted was a particularly effective introduction to phylogeny. She planned on using the activity with her students to elicit misconceptions about the relationships of organisms such as reptiles, birds, and dinosaurs, and to highlight the differences between Linnaean taxonomy and phylogenetic relationships. She planned on integrating an activity on creating cladograms based on morphological characteristics, paying particular emphasis on teaching the students that the nodes of the cladogram are reversible. She feels "like that's a very valuable thing for them to know, especially if they are going to see that somewhere on the STAAR test or the TAKS test and they'll have to evaluate the relationship" (post-interview). Stan planned on integrating an activity from the first day of the training, which distinguished between laws and theories, because previously he "never distinguished between the two" (Introduction to Geology Reflection, 2/12/11). Not only did Stan integrate the training activities into his classroom to teach evolution concepts, he also modified or planned on modifying the activities to teach other scientific concepts including the carbon cycle and identifying star types. Additional concepts all very high acceptors reported covering include conducting field experiences, the use of technology (www.digimorph.org) to compare and contrast organisms, and using dichotomous keys to identify organisms. Annie and Tammy use training activities and materials to cover the fossil record, and Stan will use activities to cover speciation by geographic isolation with his students.

Approach to teaching coding constructs different among very high acceptors. In addition to using the TEKS, very high acceptors of evolution use other methods to decide what evolutionary concepts to teach. Prior to the training Annie decided what to teach based on her own learning preference, particularly based upon what she knows and likes. She feels particularly knowledgeable about primate evolution, and would integrate activities such as comparing primate skulls to investigate functional morphology and phylogenetic relationships among primates. There were no additional applicable post-instruction constructs on how Annie decided what to teach.

Pretraining, Stan decided which evolutionary concepts he would teach by collaborating with his colleagues, though just on a cursory level. At the start of the training he had just began to share with his colleagues by discussing the topics and instructional activities he was covering. Though Stan did not collaborate extensively with his grade level colleagues, collaboration was important to him and he wanted to take a leadership role in helping assist the elementary teachers on his campus with their teaching of science. He wanted “an alignment showing the progression of how [life through time] relates to the lower grades” from the training to help teachers identify the concepts in their TEKS and appropriate activities to teach those concepts (pre-interview). Posttraining, there were no additional constructs regarding how Stan decided what he would teach.

Prior to the training, Tammy decided what to teach by collaborating with colleagues, particularly a science consultant from a local university, and by focusing on preparing students for the state-mandated standardized tests. The science consultant visited Tammy's school once a month and worked with the teachers to "weed out what [they] really need to teach" to prepare their students for the standardized assessment (pre-interview). There were no additional posttraining constructs to how Tammy decided what she would teach post-instruction.

In addition to the concept of deep time, very high acceptors teach a variety of concepts related to evolution to their students. Though it is actually a concept related to cosmology, prior to the training Annie identified the big bang theory as an evolutionary concept she discusses with her students. She also covers natural selection through exploring how populations of bacterial cultures change over time, and the nature of science by differentiating between science and religion as two different ways of knowing. Post instruction, she continued to teach natural selection to her students using the bacterial cultures lab, and also plans on teaching about phylogenetic relationships.

Prior to the training, Stan taught more evolutionary concepts than any other interviewee, including: adaptation, big bang theory, the fossil record, natural selection, the nature of science, human and chimpanzee relatedness, and speciation. He teaches several of these concepts through a simulation activity in which students predict and model what will happen over long periods of time to a population of cotton tail rabbits that becomes separated through geographical isolation. Pretraining, Stan did not integrate cladograms into his teaching, though he did emphasize the relationship between humans and chimpanzees. He focused his instruction on human and chimpanzee relationships on the fact that the two species shared a common ancestor, while dispelling the prevalent naïve notion that humans evolved from a monkey.

After the training, Stan continued to teach his students evolution concepts, including adaptations, identification and classification of organisms, deep time, natural selection, and phylogeny. However, by using an activity covered during the training he also plans on incorporating cladograms into his teaching about human and chimpanzee relationships to specifically identify the types of evidence used to determine the relationship between the two species.

Pre-instruction, Tammy says she does not cover and/or avoids teaching portions of evolution topics, specifically "Darwinian evolution" because she thinks that is "sort of forbidden in Texas" (pre-interview). While she avoids directly teaching the theory of evolution, she identified other evolution concepts related to evolution that she does teach, including adaptation, Charles Darwin and the voyage of the HMS Beagle, and speciation. She teaches adaptations through exploring the relationship between the shape of a bird's beak and what it can eat, and ties those concepts to Darwin's trip to the Galapagos Islands aboard the HMS Beagle. Posttraining, Tammy covers topics including a basic introduction of evolution, deep time, the fossil record, the nature of science, and speciation in her curriculum. When introducing evolution, she introduces it at a minimal level because teachers are required to teach TEKS and "just the bare minimum so the kids can get at least the bare minimum because they don't even get that" (post-interview). She uses Darwin's study of the Galapagos finches to investigate adaptations, the nature of science, and speciation. In teaching about deep time and the fossil record, she planned on incorporating kits and materials from the training series because they were "more visual" for the students than materials she used previously (post-interview).

In addition to differentiating between science and religion, very high acceptors used multiple methods to teach evolution concepts. Evolution is Annie's favorite subject, and prior to the training she tried to incorporate it whenever possible into her curriculum. She focused on presenting evolution in a neutral light because she remembered feeling anxious when evolution was taught to her when she was a 9th grader, and she does not want to have the same negative reaction. She approached teaching evolution through rich discussions in which students express their opinions concerning whether evolution and/or other "forms of theories of the beginning of the earth or life on earth" should be taught in schools (pre-interview). After attending the training, she continues to use rich discussions to teach evolutionary related concepts, and encourages students to have an open mind by being "open and honest" during the discussion (post-interview). She strives to be respectful of all students' beliefs when teaching evolution, even if she does not agree with them, because she does not want the students with alternate beliefs to leave her classroom feeling like they are wrong and everything they have been taught is wrong.

Similar to Annie, prior to the training, Stan tried to incorporate evolution into his classroom whenever possible because he is a "strong supporter" of the theory (pre-interview). Stan is keenly aware of common misconceptions students have about evolution, and directly addresses those misconceptions in his teaching. For example, he recognizes that students frequently have difficulty understanding the scientific meaning of the term *adapt* because they think the terms means that organisms can adapt because they need to do so. In his teaching he emphasizes that organisms are born with their adaptations, and those adaptations cannot change because the organisms needs them to. Another concept his students find to be particularly challenging is what a species is because they think species are very clearly distinct from one another, when in reality there are "huge gray areas" (pre-interview). To help students better understand what a species is, he introduces multiple species concepts into his teaching. After attending the training, Stan continues to directly address misconceptions into his teaching. He has the students distinguish between *adaptations* and *traits*, and emphasizes that natural selections occurs at the population level.

Unlike Annie and Stan, Tammy does not incorporate evolution whenever possible into her teaching. Instead, prior to the training she frequently questioned how she is supposed to teach the topic. In teaching about adaptations of birds, she "can't help but mention Darwin or the Galapagos", but does not know where "the state wants [her] to tread because [she's] from a place where the state doesn't interfere like they do here. [She doesn't] want to make too many people upset" (pre-interview). When she does introduce concepts related to evolution, she teaches them at an introductory level because her students "are really low and we don't need to give them more than they need to" (pre-interview).

After attending the training, Tammy still does not feel as though she teaches evolution in depth because she perceives the state standards require her to teach science concepts at a cursory level. When she does teach evolution concepts, such as deep time, she would approach the teaching of it by connecting directly to students' lives. For example, in teaching her students about the sequence of events that have happened over deep time, she would first have them create a timeline of their lives and then have them compare their timelines to all of the events of the past. She also would approach the teaching of the fossil record and deep time by integrating the subject areas, particularly reading and science, using materials from the training series.

Approach to teaching coding constructs consistent among moderate acceptors. Prior to the training, all moderate acceptors of evolution decided what evolution concepts they would teach using a scope and sequence; however, after the training there were no consistent constructs on how they decided what they would teach. Both moderate acceptors reported teaching deep time to their students in their pre-interviews; however since Sonja was removed from teaching science during the project, there were no consistent constructs between group members on the evolution concepts taught upon completion of the training.

Pretraining, moderate group acceptors focused their teaching on preparing their students for the state mandated standardized tests. Tara focused her instruction on the grade level science TEKS that will be tested on the state mandated standardized test, as well as reviewed tested TEKS from previous grade levels. Sonja emphasized preparing students for the standardized tests throughout her curriculum, and explains that "until we get done with the [standardized] test there's just not really anything else going on except for that" (pre-interview).

Both moderate acceptors perceive science to be less important than other subject areas, which impacts the depth and breadth of how evolution is taught in their classes. Science takes a limited role in Sonja's class. At the beginning of the year she focuses on preparing her students for the writing standardized assessment, then the reading, followed by the math, and then the science content "just gets thrown in last" (pre-interview). While Tara thinks science is important, she does not think it is a skill students need to be successful in life. Instead science "falls to the back seat when it is compared to math and reading and those skills to really get ahead in life" (pre-interview).

After the training, both moderate acceptors presented evolution concepts by using or planning on using materials and resources from the training program into their classroom curriculum. They report using activities with their students covering two aspects of macroevolution — deep time and the fossil record — as well as integrating technology applications learned in the training to compare and contrast the morphology of various organisms. Tara was able to incorporate more of the project materials into the curriculum than Sonja, and also integrated activities covering topics including: conducting field experiences; phylogeny, particularly the human and chimpanzee relatedness; and speciation.

Not only did attending the training program impact their knowledge and use of additional activities into their curriculum, it also helped moderate acceptors present evolution concepts by integrating the subject areas and/or scientific disciplines into their teaching. Sonja planned on using a dichotomous key activity from the training to help her students with writing and organizing their ideas. Prior to participating in the training, Tara would introduce plate tectonics to her students as an isolated concept. After the training, she reported feeling more comfortable in her ability to integrate multiple concepts with the teaching of plate tectonics, including dinosaur extinction, relative dating, and the law of superposition. The training program directly taught her the interrelationships among these concepts, which made her feel more comfortable teaching from an interdisciplinary perspective.

Approach to teaching coding constructs different among moderate acceptors. Similarly to the very high acceptor group, while there were consistent themes for how the moderate acceptors approached the teaching of evolution, there are also within group differences to their approach. In addition to using a scope and sequence to decide what to teach, Sonja collaborates with a colleague, though she does so with resistance. Sonja's teammate does most of the planning for instruction and then passes on the lessons to Sonja. Since Sonja was removed from science teaching prior to the end of the training series, there were no applicable constructs to how she decided what to teach, post-instruction.

Prior to instruction, Tara decides what to teach based on the TEKS. Since her 8^{th} grade students are required to take a state mandated science assessment, she primarily focuses teaching on the 8^{th} grade TEKS, though she may review TEKS from previous grade levels. Posttraining, Tara also decided what to teach based on the TEKS, but she also used a scope and sequence to guide her instruction because it has “good ideas within lessons” (post-instruction).

Before attending the training session, Sonja said she does not cover and/or avoids teaching portions of evolution topics “unless there’s something [she’s] done that [she] can’t think of” (pre-interview). After additional probing, she says she teaches adaptations which “might be related” to evolution, but could not provide any insight into the specific activities because she was not familiar with the TEKS and had not covered any of the material yet (pre-interview). Since she was removed from teaching science, there were no additional coding constructs about the evolution concepts she taught posttraining.

Prior to the training, and similarly to the very high acceptors Stan and Annie, Tara identified the big bang theory as an evolution concept she taught, though the concept is really related to cosmology. After the training she identified several additional evolution concepts she teaches including: deep time, the fossil record, and phylogeny. Though she does not think the TEKS require the teaching of evolution, she was able to integrate it into her teaching through a unit on the historical development of plate tectonic theory. During the unit she highlighted concepts including: the law of superposition, relative and absolute dating, dinosaur extinction, fossil distributions, sea floor spreading, and continental drift. Tara acknowledges learning how to integrate the concepts during the *Life Through Time* training and feels that integrating them allowed for “much more interesting conversations with my kids and some better connections were made” though she feels she does not have to teach through an integrated approach “because that’s not what the TEKS says” (post-instruction).

Prior to the training, Sonja would approach the teaching of evolution by differentiating between science and religion, though she has inconsistent views about how robust she perceives a theory to be. She thinks that evolution is the “prevailing scientific explanation for adaptations" and supports teaching only scientific concepts in her class because she is responsible for teaching what the state has "designed and decided would be taught" (pre-interview). However, she would encourage parents concerned about how evolution was being taught to discuss their beliefs at home with their child because evolution is "just one approach and, for all we know, in a few years there may be new scientific discoveries that disprove evolution" (pre-interview). Since she was removed from teaching science, there are no applicable post-instruction constructs to methods used to teach evolution.

Prior to the training Tara approached the teaching of evolution by presenting the topic in a neutral light, emphasizing that science and religion can co-exist, and trying to keep students' minds open. She does not feel her role is to tell students what to believe. Instead, she is there to "present the facts", though similarly to Sonja, she is not convinced that evolution is fact because the theory may change (pre-interview). She presents evolution and religion as able to co-exist and it "doesn't have to be one or the other" (pre-interview). Tara strives to present evolution in a way that keeps students' minds open so they are willing to listen and attempt to understand the concept, instead of causing students to shut down. Post-instruction, she teaches evolution concepts by integrating scientific disciplines in the teaching of multiple scientific contributions to the development and support of plate tectonic theory, which she learned about during the training program. She feels that not every teacher would be able to teach through the integrated approach because "not every teacher knows that stuff" (post-interview).

Approach to teaching coding constructs consistent among low acceptors. Prior to the training, all low acceptors of evolution decided what evolution concepts they would teach using the TEKS. After the training there were no consistent constructs regarding how they decided what they would teach.

Prior to the training, all low acceptors did not feel they cover and/or avoid teaching portions of evolution topics to their students. While Julianne does not feel she covers “the theory of evolution that is so controversial” with her 5th grade class (pre-interview), Joycelyn touches it “very lightly” (pre-interview). Though Teresa acknowledges covering several different concepts related to evolution with her students, she avoids specific references to actual dates of the different geological time periods, and instead refers to them as different periods of time. All three of the low acceptors agree that they teach about adaptations and recognize it is related to evolution.

Prior to the training, all of the low acceptors presented evolution concepts by incorporating creationism into at least a portion of their science curriculum. As a teacher at a Lutheran private school, Teresa teaches creationism and evolution to all of the four grade levels she teaches. She designs her curriculum using the word of God as its foundation, including teaching the seven day creation story. However, Teresa recognizes that her students will likely enter the public school system, and they need to understand scientific thinking. Thus, she presents her students a “balanced perspective” because “they both deserve time and explanation” (pre-interview). While Julianne and Joycelyn incorporate creationist reasoning into their classroom discussions, they do not integrate it as extensively as Teresa does. Instead, they introduce creationism when answering student questions about the natural world. For example, when asked by a student how the ocean got its salt, Julianne explained she thought God put it there. Joycelyn tells her students there are two “theories” about how the universe was created – the big bang theory and creationism (pre-interview).

After the training, all low acceptors presented evolution concepts by incorporating or planning on incorporating materials and/or resources from the training series into their curriculum. They incorporated activities covering the concepts of deep time, the fossil record, phylogeny, conducting field experiences, and dichotomous keys. All of the low acceptors took their students on a field trip to the Texas Memorial Museum, where portions of the training were held, and incorporated project activities into their field trip experiences. Two of the project scientists conducted presentations using specimens from TNSC's collections, covering fossils and animal adaptations for Joycelyn's and Julianne's classes. Teresa used many of the activities and materials from the training session, including referencing content learned with her students (post-interview). Though human evolution is "way out of her comfort zone", Teresa was particularly excited to share a phylogenetic activity about the relationship between humans and chimpanzees with her students (post-interview). Since Julianne was removed from teaching science mid-way through the project, she did not integrate as much of the project materials into her curriculum as the other two low acceptors. However, she did integrate an activity emphasizing the ordering of geological events, as well as discussed her experience catching water snakes during the herpetological field work day of the series.

Not only did the training impact their knowledge of different activities to teach evolution topics, it also impacted their perception of how well they teach the concepts. In describing a rock identification activity from the training she used with her students Teresa said, "I was doing it well before, but I'm just doing it with a lot more strength of understanding" (post-interview). Additionally she used stratigraphic layer models created by project staff to teach "the law of superposition really well" (post-interview). Joycelyn thought the project training materials were so effective that she actually purchased many of the same materials to use with her students. She developed an interdisciplinary project, based off of the project materials and activities, in which students explored deep time, the fossil record, and organism adaptations by becoming paleontologists going on a simulated fossil dig expedition. Once the students dug up their fossils, they had to identify them, determine their adaptations, identify how long ago the organisms lived, and use a geological map to determine where in the United States the organisms could have been found. Through integrating reading, writing, and science into her activities, Joycelyn covers scientific concepts in more depth and breadth than she had before the training. Joycelyn feels that her students love her new interdisciplinary activities. Her principal told her, "You really have some kids interested in science" (post-interview).

Approach to teaching coding constructs different among low acceptors. As with the other acceptance groups, while there were consistent themes for how the low acceptors approached the teaching of evolution, there are also within group differences to their approach. Prior to the training, in addition to using the TEKS, Julianne and Joycelyn decided what evolution concepts to teach by collaborating with colleagues and using a scope and sequence. Both Julianne and Joycelyn teach at the same school, and followed a scope and sequence developed to determine the order in which they would present the concepts. In determining the actual lessons to be taught, Julianne relied on Joycelyn to help her identify appropriate lessons to teach to her students because Joycelyn has a numerous resources (pre-interview). Posttraining, Julianne no longer teaches science so there are no applicable constructs for how she decided what to teach. After the training, Joycelyn continued to use the TEKS to guide her decisions about what to teach.

In addition to using the TEKS, prior to the training Teresa used the National Lutheran School Accreditation Standards, known as the "Standards of Faith" to decide what to teach (pre-interview). Her school's accreditation is based on using both the TEKS and Standards of Faith. She uses the Bob Jones curriculum, which integrates "biblical truth with academic excellence" to teach the Standards of Faith (BJU Press, 2013). After the training she continues to use both the TEKS and the Standards of Faith to decide what to teach. While she uses both documents to guide her teaching, she also says she has flexibility in teaching because her school doesn't require her "to adhere so strictly to them" (post-interview).

Prior to the training, there are no additional applicable constructs for the evolution concepts Julianne taught. Since she was removed from science teaching prior to the conclusion of the series, there are also no applicable constructs for the evolution concepts taught after the training.

Interestingly, Teresa, the only private school teacher of all participants and most vocal supporter of creationism, teaches evolution concepts at an earlier grade level and presents them to those grade levels in more depth than any of the other participants. Prior to the training, Teresa taught multiple evolution concepts to her students, including Charles Darwin and the theory of evolution, deep time, the fossil record, and natural selection. She introduces who Darwin was and what the theory of evolution is to her 5^{th} and 6^{th} grade classes, and then deepens the exploration of both topics in her 7^{th} and 8^{th} grade classes. She integrates field trips into her curriculum by taking her 7^{th} and 8^{th} grade students to a local cave to dig for fossils of Ice Age organisms. While she does teach evolution concepts, she continues to ensure they are presented through a creationist perspective. In discussing deep time, she asks the scientist leading the field trip to "leave out the whole thing about millions of years ago and just say changes through time" (pre-interview).

After the training, Teresa continues to teach a broad range of evolutionary concepts through a creationist perspective. While she had never seen cladograms prior to attending the training, afterwards she began teaching her students about phylogenetic relationships and how to interpret cladograms. Other evolutionary concepts she taught posttraining include: adaptations, classification and identification of organisms, deep time, the fossil record, the nature of science, and the theory of evolution.

Teresa used multiple activities from the training to teach the evolutionary concepts. For example, during a field trip to the Texas Memorial Museum, all participants were able to see a newly described sauropodomorph dinosaur, *Sarahsaurus aurifontanalis,* view cat scan data of the dinosaur, and learned how *Sarahsaurus aurifontanalis* has helped to revise scientists' understanding of dinosaur dispersal. Teresa taught her students about deep time, the fossil record, and the nature of science using project materials from the training about *Sarahsaurus aurifontanalis.* After the training she felt "definitely much more comfortable scientifically speaking to fossil evidence" of evolution (post-interview).

Prior to the training Joycelyn says she only covers evolution "lightly"; upon further probing she actually identifies several evolution concepts she teaches including: deep time, the fossil record, and inherited and learned traits. Though it is not actually an evolution concept, she also identified concepts related to cosmology, particularly the big bang theory and that fact that the sun is a star, as evolution concepts she teaches. She introduces deep time by talking about the age of the earth and how the earth has changed over time. She introduces relative dating, stratigraphic principles, and the fossil record through an activity simulating the layers of the earth. While she teaches about inherited and learned traits, she is not sure those concepts are "necessarily evolution" (pre-interview).

After the training, Joycelyn integrated more activities and materials from the training series than any other interviewee. She continued to teach deep time and the fossil record, though she did so in much more depth and breadth than she had before, and taught those concepts using materials from the training. She began to introduce phylogenetic concepts by asking students to predict what the descendants of extinct organisms would be, assuming they were living today. She began introducing concepts related to natural selection, including variation, differential survival of organisms, and inheritance of traits. Joycelyn planned on borrowing a bird skull kit from the training series to teach her students about animal adaptations and form and function. She taught those concepts prior to the training; however she did not feel that she presented them in depth, so that the students fully understood where the birds lived and why they lived where they did. The training helped her realize she frequently taught scientific concepts on a cursory level, and often ran out of time for the "kids to really understand why it's that way" (post-interview). She plans on spending more time teaching her students in depth by covering why things are the way they are.

Prior to the training Julianne approached the teaching of evolution by teaching concepts in isolation. She struggled with understanding how earth and life science concepts relate, and perceived the TEKS to separate the two disciplines. After the training, Julianne was removed from science teaching and was unable to teach many of the concepts. However, she tried to integrate as much of the training materials and concepts as possible into her reading curriculum. She thinks it is important to approach teaching evolution concepts by encouraging students to have an open mind, and by clarifying she is not going to tell them how to believe. Instead, she is just presenting evidence and they can make up their own minds. She also thinks it is important to teach evolution concepts by connecting to students' experiences. To help her students conceptualize deep time, she would first have them think about how they have changed during their own life spans, then compare that with how their city has changed over several decades, and then compare that to all of geologic time.

Prior to the training Teresa approached the teaching of evolution through a creationist perspective. She taught her students that microevolution occurs, but not macroevolution. In her perspective microevolution makes sense because "things have to survive"; but macroevolution does not make sense because "God created each individual thing in an individual time" (pre-interview). Though she clearly teaches her students her creationist perspective, she encourages them to have an open mind to determine if they accept evolution for themselves. She tells them "don't be afraid" to explore evolution because some of the evidence for it, like DNA evidence, is "so good" (pre-interview). While she encourages exploration of both evolution and creationism, Teresa teaches that no one ever really knows what happened. She explains (pre-interview),

> If you meet a Christian who says they know exactly how it happened, they're lying. If you meet a scientist that says they know exactly how it happened, they're lying. Nobody really knows. We're all just taking our best guess.

Teresa feels her students need to be prepared to take a side because there are consequences to believing in creationism. One way she prepares students is by the use of rich discussions. If parents were concerned about their child learning about evolution, she would allow the student to be pulled from her class and/or would show the parents the content being presented.

Posttraining, Teresa reported using many of the same methods to teach evolution. She continued to incorporate creationism into her teaching, but encouraged her students to have an open mind towards evolution. She stressed that her students needed to educate themselves more before they decided not to embrace it. She would encourage her students to talk to their parents about the belief system their family supports.

Prior to the training, there are no additional applicable constructs for the methods Joycelyn used to teach evolution. After the training, she approached the teaching of evolution by integrating subject areas and scientific disciplines. Every year she has students who disagree with the evolution concepts taught, including the age of the earth, because they perceive them to conflict with the Bible. Joycelyn informs the concerned students that she agrees with the Bible, but possibly the time scale of the Bible should not be interpreted literally. After the training Joycelyn still has misconceptions about what exactly evolution is, and perpetuates that misconception to her students. She tells them if they do not want to call the process *evolution*, they can call it *adaptation* “because it’s the same type of concept” (pre-interview).

Summary for approach to teaching evolution. Participants across all acceptance levels reported teaching a broad range of topics related to evolution. Both before and after the training, participants tended to teach concepts related to macroevolution, particularly deep time, the fossil record, and the nature of science, more frequently than teaching microevolutionary concepts. After the training interviewees in the very high and low acceptance groups reported they began introducing phylogenetic relationships into their curriculum, specifically using activities in materials from the *Life Through Time* series. Very high acceptors emphasized the importance of differentiating between science and religion in teaching evolution. Moderate acceptors focused on preparing their students to take the state mandated standardized tests, and perceived science to be a less important subject than other areas. All low acceptors of evolution incorporated creationist concepts into their teaching when they taught evolutionary concepts. Though there were differences among all interviewees, all participants reported incorporating materials and/or resources from the training series into their curriculum. Several of the participants reported feeling more confident, knowledgeable, and/or prepared to teaching evolution as a result of attending the training.

Challenges to teaching evolution. Teachers’ descriptions of the challenges they had to teaching evolution, and how they would respond to those challenges provide insight into teachers’ perceptions of the role of evolution in their class, both before and after the training. To explore participants’ perceptions of the challenges to teach evolution, participants were asked how they would respond to a student asking if the teacher believed in evolution, to identify the most challenging aspects about teaching evolution, and how they would respond to a parent concerned about how evolution was taught in their class. A cross-acceptance group comparison of coding constructs consistent among acceptance groups for their reported challenges to teaching evolution will be presented first, followed by a within acceptance group comparison of coding constructs different among the acceptance group.

Table 49 presents a comparison of the coding constructs consistent among the teachers in each acceptance group for their reported challenges to teaching evolution, both before and after the training. Of particular note is that the only consistency among every acceptance group is their perception that the most challenging aspect of teaching evolution are the content challenges.

Table 49

Comparing Coding Constructs Consistent Among Acceptance Groups for Challenges to Teaching Evolution

	Belief in evolution	**Most challenging aspects**	**Concerns about how evolution is taught**
Very High Acceptors			
Pre-instruction: consistent constructs	▪ no applicable constructs	▪ content challenges ▪ perceived conflict between evolution and religion	▪ no applicable constructs
Post-instruction: consistent constructs	▪ no applicable constructs	▪ content challenges	▪ differentiates between science and religion
Moderate Acceptors			
Pre-instruction: consistent constructs	▪ no applicable constructs	▪ content challenges ▪ student background	▪ no applicable constructs
Post-instruction: consistent constructs	▪ no applicable constructs	▪ content challenges ▪ student background	▪ no applicable constructs
Low Acceptors			
Pre-instruction: consistent constructs	▪ no applicable constructs	▪ content challenges	▪ no applicable constructs
Post-instruction: consistent constructs	▪ no applicable constructs	▪ no applicable constructs	▪ no applicable constructs

Challenges to teaching coding constructs consistent among very high acceptors. Prior to the training, there are no consistent constructs for how the very high acceptors would respond to a student who asked if they believed in evolution. There were no consistent posttraining belief in evolution constructs either.

Prior to the training, very high acceptors consistently reported the most challenging aspects of teaching evolution are the content challenges and the perceived conflict between evolution and religion. The content challenges relate to macroevolutionary concepts including teaching about deep time, the fossil record, the nature of science, and speciation. Tammy perceives teaching about deep time and the fossil record to be challenging because "students don't have enough of the knowledge base of the fossils and all those creatures that lived long ago" (pre-interview). Some of Stan's students do not accept the scientific explanation for the age of the earth to be 4.6 billion years, and instead think the earth is 10,000 years old. All very high acceptors report their students do not understand the geological timescale because of the scale of the numbers. Tammy and Stan find their lack of resources to be challenging to teach about deep time and the fossil record, particularly because they do not have access to high quality fossil specimens to share with their students, and instead have to rely on pictures and illustrations of fossils to teach concepts. Stan identifies the most conceptual challenges of any other interviewee. His students have challenges understanding the nature of science, particularly the robustness of a theory, and that theories are based on multiple lines of evidence. His students also have challenges understanding how speciation occurs, including how species change over time and the definition of a species Additional content challenges Stan identified include challenging vocabulary associated with evolution, and persistent misconceptions.

Prior to the training, the perceived conflict between evolution and religion impacts very high acceptors teaching of evolution. Annie finds it challenging to present evolution without offending the students, particularly because she used to be a student who did not believe in evolution. Both Annie and Tammy find it challenging that students dismiss the concepts prior to learning about them because they perceive the concepts to be counter to their beliefs.

After the training, very high acceptors continued to identify challenging content as being a main challenge to teaching evolution. Identified content challenges surrounding macroevolution include: the notion that species are immutable, lack of acceptance of human evolution and/or macroevolution, and trouble conceptualizing deep time or scale. Stan thought a simulation activity from the training program which emphasized natural selection and speciation via geographical isolation would be effective to address students' lack of acceptance of macroevolution. Very high acceptors continued to identify vocabulary, including the meanings of *adaptations* and *traits,* as being challenging to understanding evolution, as well as persistent misconceptions, such as individuals versus populations evolving and that organisms can adapt because they need to do so.

Prior to the training, there were no consistent constructs among very high acceptors regarding addressing parental concerns about how evolution was taught in their classes. Post-instruction very high acceptors would address concerns by explaining they differentiate between science and religion in their class. They would emphasize that theories are testable, measurable, and based on evidence, while religion is based on belief. While Annie tells her students they do not have to believe in evolution, but they do have to understand it, Tammy seems frustrated by the fact that some of her students will listen to her teaching of evolution and will answer questions correctly on a test, but "aren't buying into it" (post-interview).

Challenges to teaching coding constructs different among very high acceptors. While there are consistencies within each acceptance group about their awareness of and response to challenges they face in teaching evolution, there are also differences among the group members. Presented below is a discussion of the coding constructs that were different among very high acceptors.

Very high acceptors were aware of and would respond to challenges to teaching evolution in different ways. Prior to the training, if a student asked Annie if she believed in evolution, she would say yes, but would differentiate between belief and acceptance to the student. Evolution is not a matter of belief for Annie; instead it is a "matter of logic" (pre-interview). According to Annie,

> People again can believe whatever kind of crazy things that they want but this is actually just a concept or a theory that explains as best that we can, the evidence we see. Where it may be wrong, it's been verified numerous of thousands of times probably over the past couple of hundred years maybe. I would try to say that yes, this is what I value as… I don't know if I want to go with the word truth, but I may try to make that slide because that's kind of how people speak. I try to be careful with my speech, but sometimes you just say things. I would say yes, I do believe it's true, but I don't believe it's a believing characteristic. I think it's something that you can find evidence for and that it's a fact based concept (pre-interview).

After the training, Annie would respond to a student inquiring if she believed in evolution by saying yes, she thinks evolution happened. Annie recognizes that using the word *believe* when referring to evolution may be problematic because evolution is not a matter of belief. However, she attended church for her entire young adult life, and "knows it's just semantics what you call it" (post-interview.) She would also reinforce to the student that they can accept evolution, without having to reject their belief in God.

Prior to the training, Stan would reply to a student inquiring if he believed in evolution by saying yes, he is a "firm believer in the process of science" (pre-interview). In his view, since evolution is supported by science, it supports his belief system in terms of science explaining the world. However, the training greatly impacted how he would respond to the student inquiry. Posttraining, Stan thinks the term *believe* has no place in the sentence. Instead, he would tell the student he accepts evolution, but would clearly differentiate between belief and acceptance to the student using phrasing from a training activity covering the nature of science. In his explanation he would emphasize that evolution is not a belief system. Instead, it is system which explains how processes work, and is measurable, reliable, and repeatable.

Both before and after the training, Tammy would remain neutral if a student asked if she believed in evolution. She would respond that she is just teaching the lesson, and she cannot discuss her beliefs with him/her.

While there were consistencies in the constructs the high acceptors identified as being the most challenging aspects of teaching evolution, there were also differences in their identified constructs. Prior to training, there were no additional applicable constructs to Annie's perceptions of the most challenging aspects of teaching evolution. After the training, she identified the combined effect of the perceived conflict between evolution and religion and the fact that evolution may be too complicated for people to understand to be major challenges to teaching evolution. When teaching evolution, she often feels she is "doing the opposite of preaching to the choir," and that sometimes her teaching "falls on deaf ears," either because the concepts are too complex or because students just do not try.

Pretraining, Stan perceived there to be political resistance to teaching evolution in Texas, in which there were efforts to "water down the TEKS," which made the teaching of it particularly challenging (pre-interview). Another challenge he identified was parental concerns about teachers forcing students to believe in evolution.

Stan thought the most exciting part of the whole training series was the exploration of the Tree of Life and phylogenetic relationships because it covered concepts with which he was unfamiliar. After the training, Stan was particularly frustrated that the TEKS required teachers to teach from an outdated "form of classification" because they emphasize teaching students relationships based on Linnaean taxonomy instead of based on phylogeny (post-interview). He questioned how he could change governmental policies to restructure what he is supposed to teach to incorporate additional evolutionary concepts. While Stan's school supports his teaching of evolutionary concepts, he recognizes that others are "afraid for teachers to say the word evolution" (post-interview), which impacts how evolution is taught throughout Texas.

Before the training, Tammy's biggest challenge was being unsure of how to address evolution. Previously, she taught in a place where the "state doesn't interfere like they do here"; thus she is not sure how the Texas Education Agency wants evolution addressed (pre-interview). She also found the TEKS to be vague, and found it hard to narrow down exactly what science concepts and examples to use when teaching specific TEKS. An additional challenge to teaching evolution Tammy identified was that her students' knowledge base is limited, and they "don't have a lot of experience," which makes evolution hard for them to grasp (pre-interview).

After the training, Tammy identified several aspects of her students' background which made the teaching of evolution challenging, including: they are not motivated, they are not used to labs or participating in activities, they have limited experience with higher order thinking, they have a limited knowledge base, and they resist new things. Her students' previous teachers taught science using worksheets and do not teach similar content as Tammy, so when she tries to give them "anything outside the box, they have a hard time with it" (post-interview). Adding to the problem of limited student experience is the lack of parental support Tammy perceives both she and her students receive. Tammy finds the perceived conflict between science and religion to be a challenge, and is particularly frustrated that her students can understand the evolution concepts presented, but choose not to accept them. Similarly to Stan, Tammy identifies the TEKS as being a challenge to teaching evolution, though Tammy feels the TEKS only require the bare minimum to be taught, and they do not require teachers to teach for depth of understanding.

Both before and after the training, the very high acceptors would respond differently to a concerned parent about how evolution was taught in the class. Prior to instruction, Annie would explain to a concerned parent that evolution is a robust theory, and that students need to understand evolution to be scientifically literate. She would explain that students are free to believe what they want, but evolution "is the current scientific thought and there's no really competitive theory at all" (pre-interview). After the training, Annie continued her stance that students have to understand evolution, not believe in it.

Prior to the training, Stan would respond to a concerned parent about how evolution is taught in his class by providing an overview of the nature of science, and summarizing how evolution is approached in his class. He would also explain that the concepts are part of the TEKS. While he would allow a student to be pulled from the class in which evolution was presented, he would ensure the parent was aware of the consequences of the student missing the material, such as missing questions on the state mandated standardized test. After the training, Stan would address a parent or student's concerns about how evolution is taught in class by differentiating between science, which is evidence-based, and religion, which is belief-based.

Pretraining, Tammy would address parental concerns about the way evolution is taught in her class by explaining she teaches science concepts, which are based on evidence, as opposed to religious concepts, which are based on belief. After the training, Tammy would address concerns in a similar manner by explaining that theories are based on evidence, they are testable by observation and experiment, and there is a lot of evidence to support them.

Challenges to teaching coding constructs consistent among moderate acceptors. Prior to the training, there were no consistent constructs among the moderate acceptance group for how they would respond to a student who asked if they believed in evolution. There were no consistent posttraining constructs for belief in evolution either.

Pretraining, moderate acceptors reported the most challenging aspects of teaching evolution include challenging content and their students' background. Content challenges identified included the macroevolutionary concept of deep time. Tara and Sonja's students have trouble understanding just how long geological processes take. Sonja feels her students' conception of time is limited because they have only been alive for such a short period of time. Moderate acceptors also identified their students' backgrounds as being a challenge. Half of Tara's students have a parent in the military; thus, her population of students is highly mobile. Tara has to spend much of her time reviewing concepts because the students may have never been introduced to them before. Sonja's says her students' backgrounds are challenging because they are bilingual, and it takes them longer to process the language parts associated with learning the content; thus, she has to spend more time on learning the content than it would take native English speakers (pre-interview).

After the training, moderate acceptors continued to report the most challenging aspects of teaching evolution include challenging content and their students' background. Not only did the moderate acceptors identify deep time as conceptually challenging, but they also identified concepts related to the nature of science and phylogeny. Tara's students do not have a clear understanding of phylogeny. Her students have the persistent misconception that humans "came from chimpanzees," and she feels as though the way science is presented in popular culture reinforces that misconception. Though Tara tried to dispel the misconception, even after discussing that humans are related to chimpanzees not descendants of them, many students retained the notion. Aspects of students' background that Tara found to be challenging include a lack of student motivation, students' limited knowledge base and limited life experience, and that students want to hold onto their beliefs, even if presented with information contrary to them. The most challenging aspect of student background Sonja identified was that students are not used to reading about science and had trouble identifying the main idea of a passage.

Prior to the training, there were no consistent constructs for how moderate acceptors would respond to a parent or student concerned about how evolution was taught in their classes. There were no consistent posttraining constructs for responding to a concerned parent or student either.

Challenges to teaching coding constructs different among moderate acceptors. Moderate acceptors of evolution responded differently to the challenges they face in teaching evolution, and how they would respond to those challenges. Both prior to and after attending the training series, Sonja would respond to a student asking if she believed in evolution by offering no definitive answer, though she would explain that evolution is based on science. Prior to the training, Sonja explains that evolution is the "prevailing scientific explanation for adaptations," and that is what she will "support in class" (pre-interview). After the training she continues to accept that evolution is the prevailing scientific explanation, but inserts some tentativeness into her answer by explaining that evolutionary theory is "constantly being reevaluated based on new evidence" (post-interview).

Prior to the training Tara would tell a student asking if she believed in evolution, that she does, though she thinks God had a role in the process. After the training, Tara continued to believe in both science and religion, and feels that people do not "have to give up beliefs in God to believe in evolution as well. They can co-exist" (post-interview).

Sonja identified additional challenges to the teaching of evolution prior to the training series, including teachers having limited science background knowledge and time restrictions preventing her from teaching science. Sonja repeatedly remarked that she is "not really prepared to teach science," and only had to pass a test to become an elementary teacher, even though that does not mean she is actually qualified to teach it. She feels science teachers need to be better prepared to teach than she is, particularly to help students compete in a global economy that relies on knowledge of math and science.

After the series, Sonja identified teacher frustrations as a primary challenge to teaching evolution. Time limitations greatly impact her teaching, and she has "no time to finish anything and there's no time for anything extra" (post-interview). She also feels that teaching is overwhelming, and every year she has to work more, but gets less accomplished. The requirements keep changing, and she is having trouble keeping up with understanding and implementing the changes. Sonja feels "there's no catching up" (post-interview).

Pretraining, additional challenges to teaching evolution that Tara identified pertain to the perceived conflict between evolution and religion. She is concerned about teaching evolution concepts because she does not want to go against parental teachings if the "parents have a certain idea they want them to believe" (pre-interview). She also finds it challenging to present the concepts without offending students, particularly those who think evolution is wrong.

After the training, the challenges Tara faces in the teaching of evolution continue to be centered on the perceived conflict between evolution and religion. She finds it challenging to counter students' perceptions that accepting evolution and believing in God cannot co-exist. She thinks teaching evolution is particularly challenging because children are often taught religion from birth, and students struggle accommodating evolution, which is typically introduced much later, into their pre-existing conceptions of how the world works. She explained,

> We don't teach evolution from birth and so when evolution is introduced, it's really hard for them to put that in their mind that it is as believable as God. When you teach something from that young, that they're raised that that is true and that's just the way it is and that's the way it's going to be. Evolution is not taught the same way. It's a harder concept for them to grasp and put in with what they already know about God (post-interview).

Moderate acceptors of evolution would respond to concerned parents or students about how evolution was taught in their classes in different ways. Prior to the training, Sonja would explain that she is teaching what the state decided would be taught and would encourage parents to discuss their beliefs with the student. She also explains that while she is teaching the current scientific viewpoint, that new scientific discoveries may be made that disprove evolution. There were no applicable posttraining constructs for how Sonja would respond to concerns about how evolution is presented in her class.

Pretraining, Tara would address concerns about how evolution was taught in her class by explaining that evolution and religion can co-exist, and that she is not teaching students that evolution is correct or that students should believe in it. Instead, she explains she is there to "present all the facts about what we know and what the current theory is," but the theory may change (pre-interview).

After the training, Tara has a more accurate understanding of the robustness of a theory, and would respond to a concerned parent by emphasizing that theories are based on evidence. She explains theories do not come "out of thin air," and they are "more than just a thought process." They are "real and true and…that's just the way it is" (post-interview). While she accepts evolution to be true, she would address concerns about how it is taught in class by telling students she does not really teach evolutionary concepts in depth, and when she does teach them, the students do not have to believe in them.

Challenges to teaching coding constructs consistent among low acceptors. There were no consistent constructs among the low acceptance group for how they would respond to a student who asked if they believed in evolution, prior to the training. There also were no consistent posttraining constructs for belief in evolution either.

Prior to the training series, all low acceptors of evolution agreed that specific challenges to the teaching and understanding of macroevolutionary concepts were challenging aspects of teaching evolution. Teresa questioned how scientists determine the age of the earth and the validity of radiometric dating in accurately determining the age of rocks. While she believes that radiometric decay occurs, she has a "problem sticking actual numbers" to the half-lives (pre-interview). When her students ask how scientists know their dating methods are accurate, she tells them she does "not know why they think they know that" (pre-interview). Many of Teresa's students do not accept human evolution, and "a lot of them are very appalled to think that man came from a monkey" (pre-interview). Both Joycelyn and Julianne's students have trouble understanding the concept of deep time because they do not have a firm understanding of the notion of time, and events that happened before they were born. There were no applicable consistent posttraining constructs for low acceptors' challenges to teaching evolution.

There were no consistent pretraining constructs for how low acceptors responded to a concerned parent about how evolution was taught in their classes. There were no consistent posttraining constructs for low acceptors' responses to concerns about how evolution was taught in their class.

Challenges to teaching coding constructs different among low acceptors. Low acceptors of evolution also identified different challenges to teaching evolution, as well as how they would respond to those challenges. Prior to instruction, when asked by a student if she believes in evolution, Julianne would not provide a definitive answer, but would explain that evolution is based on science and that she supports the Darwinian notion of "survival of the fittest" (pre-interview). After the training Julianne continued to have an alternate understanding of the definition of evolution, and equated evolution with change occurring over time. She would respond to a student asking if she believes in evolution by saying that she accepts that change over time occurs.

Both before and after the training Teresa would respond to a student inquiry if she believes in evolution by telling the student that she believes in parts of it, but not others. Pretraining, she accepts that microevolution occurs. She thinks that "species can change within species and that the stronger adaptation will eventually take over" (pre-interview). However, she does not believe in macroevolution because she does not "believe that things evolved from one genus to another," such as whales evolving from hoofed land mammals (pre-interview).

After the training she still does not accept macroevolution, and would tell students she does not believe "we started from primordial slime," nor will she ever "come to an agreement on the whole man and monkey thing" (post-interview). However, she does believe there are aspects of evolution that are "irrefutable," and that students need to understand there has been change over time in non-human animals and plants.

Similarly to Teresa, prior to the training, Joycelyn would tell a student questioning if she believes in evolution that she believes in parts of it, but not others. She has particular difficulty understanding how one species could evolve into another species, and "how plants and animals came out of dirt when there wasn't anything to begin with" (pre-interview). While her primary challenge is in understanding macroevolutionary concepts, she completely agrees with the microevolutionary concept of survival of the fittest because "yes, the strongest, the most camouflaged, the most hardy, whatever they are going to be the ones that survive. Of course they are going to have offspring" (pre-interview).

After the training, Joycelyn's response about believing in evolution changed. She would tell a student that she believes in both science and religion, and just because a person believes in evolution, that does not mean he/she is an atheist.

Low acceptors identified different aspects related to the teaching of evolution to be the most challenging. Prior to the training, Julianne said that many evolution concepts are abstract, which makes them challenging to teach. Her students are concrete thinkers and understand concepts better when they can explore them using their five senses. However, Julianne thinks that "a lot of science is abstract thinking," which makes it difficult to teach (pre-interview).

After the training Julianne identified challenges in understanding macroevolution, particularly the concept of time span and deep time, to be particularly challenging. She also identified having a lack of materials to teach labs to be problematic, especially at her campus because all seven of the science teachers were supposed to share lab materials to teach the concepts at exactly the same time.

Prior to the training, Teresa identified several challenges surrounding the teaching of evolution centered on the perceived conflict between religion and science. She teaches her students there may be negative consequences to believing in creationism, such scientists who believe in intelligent design being “shooed away” from the scientific community, and doctors who reference God being laughed at in medical conventions. While she perceives there to be consequences to believing in creationism, she encourages her students not be concerned about voicing their creationist perspectives in an open forum. Another challenge to teaching evolution is that Teresa’s students feel that parts of evolution are refutable, which may cause the students to avoid or not engage in exploring the topic. However, though some of Teresa’s students do not accept human evolution, she encourages them to explore the topic by examining both the scientific evidence and the teaching of the Bible.

After the training, the most challenging aspect of teaching evolution for Teresa was confronting students’ “fear” of learning about evolution (posttraining). She tells her reluctant students that evolution is “not necessarily horrible,” and “there’s so much to it that [they] should embrace” (post-interview).

Pretraining there were no additional applicable constructs to the challenges Joycelyn identified to the teaching of evolution. Posttraining, Joycelyn identified the macroevolutionary topic of deep time to be particularly challenging for her students, particularly the age of the earth. Another challenge Joycelyn identified was the perception that evolution and belief in God cannot co-exist. She found this concept to be particularly challenging when talking with her husband about what she learned in the training. Her husband was concerned about the impact the training had on her belief in

God, and questioned her learning additional science content because he was worried learning more may cause her to reject her belief in God.

All low acceptors would respond differently to a parent's concerns about how evolution is taught in the class. Prior to the training, Julianne would explain to the concerned individual that the focus of the class is on adaptations, and that she does not really teach evolution. Posttraining, she would explain that she is not telling students what to believe; instead, she is just presenting evidence and they "can make up their own mind" (post-interview).

Pretraining, Teresa would address a parent's concerns about how evolution is being taught by ensuring the parent knows her bias in presenting creationist material during the science course. She would summarize how evolution was taught in her class, and explain she teaches both evolution and creationism in the same course. She would invite the parent to attend the class where evolution was taught, and also allow the parent to remove the student from the class in which the content was presented. Post-instruction, Teresa would respond to a concerned individual about how evolution was being presented by saying the students have to understand evolution, not believe in it.

Before attending the training, Joycelyn would respond to a concerned parent about how evolution was presented in her class by saying she does not teach evolution in depth. After the training she would explain that she is teaching what scientists know or feel is correct, and that students can call evolution *adaptation* because "it's the same type of concept" (post-interview).

Summary for challenges to teaching evolution. Participants across all acceptance levels reported a broad range of challenges they face in teaching evolution, and respond to those challenges in different ways. Both before and after the training, the majority of the interviewees believed in at least some aspects of evolution. None of the participants said they did not believe in evolution. Instead, one of the teachers remained neutral and said she cannot discuss her beliefs with her students. Prior to the training, the two low acceptors who believe only parts of evolution, believe in microevolutionary processes, not macroevolutionary ones.

Prior to the training, participants across all acceptance groups identified content challenges, particularly challenges understanding concepts related to macroevolution, to be particularly problematic in the teaching of evolution. The high acceptors also consistently identified the perceived conflict between evolution and religion to be particularly challenging, while moderate acceptors consistently said that their students' background made it challenging to teach evolution.

Though there were not many consistent constructs among acceptance groups on how they would respond to a concerned parent about how evolution was taught in their classes, high acceptors consistently reported after the training that they would be sure they differentiate between science and religion for the concerned individual. After the training, participants from each acceptance group would try to alleviate the parent's concerns by explaining that religion and evolution can co-exist, or by explaining students need to understand evolution, not believe in it. Prior to the training, two of the low acceptors, Joycelyn and Julianne, would explain to parents that they do not really teach evolution. Posttraining, Joycelyn taught substantially more evolution-related concepts and incorporated more activities from the *Life Through Time* training than any other participant.

Pedagogical content knowledge about teaching macroevolution. Teachers' responses to scenarios exploring their pedagogical content knowledge about macroevolution provided insight into how teachers would teach evolution in their classes, both before and after the training. To explore participants' macroevolution pedagogical content knowledge, participants were asked to respond to scenarios about how they would teach or respond to student questions about the macroevolution concepts assessed on the MUM. The macroevolutionary concepts covered included: the nature of science, phylogeny, speciation, deep time, and fossils. A cross-acceptance group comparison of coding constructs consistent among each acceptance group for their macroevolutionary PCK will be presented first, followed by a within-acceptance group comparison of coding constructs different among each acceptance group. Tables 50 and 51 present a comparison of the coding constructs consistent among the teachers in each acceptance group for their PCK about teaching macroevolution, both before and after the training.

Table 50

Comparing Coding Constructs Consistent Among Acceptance Groups for PCK

	Nature of science	**Fossils**	**Phylogeny**
Very High Acceptors			
Pre-instruction: consistent constructs	▪ theories are based on evidence	▪ land was previously covered with water, and earth's surface changed over time	▪ cladogram shows ▪ relatedness of different species

Post-instruction: consistent constructs	▪ no applicable constructs	▪ gaps caused by fossilization bias	▪ cladogram shows
			  ▪ great apes & monkeys continue to evolve
			  ▪ humans & chimps evolved from a common ancestor

Moderate Acceptors			
Pre-instruction: consistent constructs	▪ theories are speculative	▪ land was previously covered with water, and earth's surface changed over time	▪ cladogram shows ▪ relatedness of different species

Post-instruction: consistent constructs	▪ no applicable constructs	▪ no applicable constructs	▪ cladogram shows
			  ▪ humans & chimps evolved from a common ancestor
			▪ use and/or reference training activities
			▪ evidence for cladogram is based on/supported by
			  ▪ genetic evidence
			  ▪ morphological characteristics

Low Acceptors			

Pre-instruction: consistent constructs	▪ theories are speculative	▪ land was previously covered with water, and earth's surface changed over long periods of time	▪ relationship of chimpanzee & bonobo on cladogram indicate
			  ▪ they are closely related
			▪ cladogram shows
			  ▪ relatedness of different species
			▪ evidence for cladogram is based on/supported by
			  ▪ morphological characteristics

Post-instruction: consistent constructs	▪ no applicable constructs	▪ no applicable constructs	▪ no applicable constructs

Table 51

Comparing Coding Constructs Consistent Among Acceptance Groups for PCK, Continued

	Deep Time	**Speciation**
Very High Acceptors		
Pre-instruction: consistent constructs	▪ conceptual challenges ▪ students do not understand long lengths of time	▪ no applicable constructs
Post-instruction: consistent constructs	▪ use activity from training	▪ emphasis of activity is on geographic isolation
Moderate Acceptors		
Pre-instruction: consistent constructs	▪ conceptual challenges ▪ students do not understand long lengths of time	▪ emphasis on how environment shapes animal's adaptations
Post-instruction: consistent constructs	▪ use activity from training	▪ no applicable constructs
Low Acceptors		
Pre-instruction: consistent constructs	▪ no applicable constructs	▪ emphasis of activity is on limited natural resources or food choice affects what birds eat
Post-instruction: consistent constructs	▪ use activity from training	▪ effect of training on understanding or approach to teaching ▪ could/will use speciation lab from LTT activity ▪ emphasis in activity based on training resource is on ▪ geographical isolation

Nature of science PCK coding constructs consistent among very high acceptors. To explore participants' PCK about the nature of science, during the pre-interview all interviewees were asked how they would respond to a student who said that evolution was "just a theory." This particular interview question was designed to assess the components of PCK identified by Magnusson et al. (1999) related to participants' knowledge about students' understanding of the nature of science, and their knowledge about instructional strategies for teaching the nature of science. Very high acceptors consistently held an accurate understanding of the nature of science and replied that they would tell the student that theories are based on evidence. Tammy would tell her students they were going to examine all the evidence supporting the theory. Stan explores the topic in further depth by explaining that evolution is "supported by evidence from all different areas" including concepts such as: extant organisms, the age of the earth, astronomy, physics, and radiometric dating (pre-interview). Annie explains to her students there are all these "facts" people can see that provide evidence for evolution, including populations changing over time and transitional fossils documented in the fossil record. She would further explain there is no scientific evidence supporting Biblical events such as "massive destructive event… like a giant flood where half the animals died" (pre-interview).

To explore participants' posttraining nature of science PCK, interviewees were asked to select which description from a choice of four of how scientists do their work they agree with most and justify their selection. This interview question was designed to elicit participants' PCK related to their knowledge about students' understanding of the nature of science, and their knowledge about instructional strategies for teaching the nature of science. There were no applicable consistent post-interview construct for the very high acceptors.

Nature of science PCK coding constructs different among very high acceptors. While there were consistencies among acceptance groups for their PCK about the nature of science, there were also differences in responses among group members. Presented below is a discussion of the coding constructs that were different among very high acceptors.

In addition to understanding that theories are based on evidence, high acceptors had other constructs about their nature of science PCK. Prior to the training, Annie had a firm understanding of the robustness of a theory, and the notion that the extra-scientific meaning of *theory* often poses problems for students understanding the nature of science. When asked how she would respond to a student who said evolution was “just a theory”, Annie would tell the student that evolution is not “just” a theory, and the word *just* has no place in that sentence. She would differentiate between scientific and colloquial definitions of *theory* for the student, and would define the scientific meaning of *theory* by saying it is “a concept that ties a lot of facts together” (pre-interview). After the training, Annie had a firm understanding that there is not a single scientific method that all scientists follow, and instead understands that scientists use different methods depending on their question. She also teaches her students the three different types of scientific investigations the TEKS require – the comparative method, experimental method, and descriptive investigations.

Prior to the training, Stan also had a firm understanding of the nature of science, particularly that theories are robust, and that students’ alternate conceptions about the meaning of *theory* often poses a problem for students in understanding the nature of science. He would explain to a student questioning if evolution is “just a theory” by stating that theories explain how things work in nature, and then would differentiate between scientific and colloquial definitions of theory. Post training, Stan continued to have a firm understanding of the nature of science regarding how scientists conduct scientific investigations. He agrees that scientists use different methods depending on their question and that “not all scientists follow the scientific method” (posttraining). For example, he specifies that many scientists do not conduct experiments, which is typically the way that the scientific method is presented to students, such as geologists who study deep time or biologists who study blue whale behavior.

Prior to the training, there were no additional constructs for Tammy's nature of science PCK, other than her recognition that theories are based on evidence. After the training, Tammy still held an alternative conception about the nature of science and the scientific method. Of the four answer choices, she agreed mostly with the statement that all scientists follow a definite set of steps in performing the scientific method. She reinforces the misconception that there is a singular scientific method to her students by requiring them to participate in science fair, and only allowing them to conduct experiments for their science fair projects.

Nature of science PCK coding constructs consistent among moderate acceptors. Prior to the training, moderate evolution acceptors consistently would respond to a student who said evolution was "just a theory" by explaining that theories are tentative, and are always subject to change. Tara would not disagree that evolution is "just a theory" because,

> Everything in science is pretty much a theory because we don't know everything yet. There are many things in the past that we have come, that we've had theories and they thought was right at the time and as we've found out more, we've changed our thoughts and changed our theories about it (pre-interview).

Sonja says theories are speculative because there are always new discoveries, which may either disprove or further support evolutionary theory. There were no applicable consistent post-interview constructs for the moderate acceptors.

Nature of science PCK coding constructs different among moderate acceptors. In addition to thinking that theories are speculative, moderate acceptors had other constructs related to their PCK about the nature of science. Prior to the training, there were no additional constructs for Sonja's nature of science PCK, other than her misconception about the speculative nature of theories. After the training, Sonja correctly identified that scientists use different methods depending on their question, but could not elaborate on why she choose that response over the others.

Prior to the training, Tara held several naïve notions about the nature of science, and the robustness of a theory. In addition to thinking theories are speculative, she thinks that evolution "can be more than a theory as we learn more" (pre-interview). She thinks that concepts in science can be proven right, though "very, very few things" have been proven so. Tara still retains misconceptions about the nature of science and presents the nature of science in a manner that will reinforce the misconception with her students. She thinks that scientists follow a definite set of steps in performing the scientific method, and reinforces that conception in her teaching. Historically her students were required to participate in science fair, and had to conduct experiments as part of their project. She is now required to teach her 8th grade students about experimental design for an entire four week period, and does not cover other methods.

Nature of science PCK coding constructs consistent among low acceptors. Similarly to the moderate acceptors, low evolution acceptors consistently would respond to a student saying evolution is "just a theory" by explaining that theories are speculative, and subject to change. Joycelyn explains that people have not directly observed events that happened prior to our existence, so we cannot be sure that evolution happened. Julia thinks that evolution will remain a theory until someone introduces a piece of evidence that is counter to scientists' current understanding. Annie acknowledges that theories are based on observations that have been made and documented, but they have not been proven wrong or right. According to Annie, theories may change when God allows people to "know more about him and how he orders things as he so chooses" (pre-interview). She agrees that even the theory of relativity, which she thinks is “very true,” could be proven not to be. There were no applicable consistent post-interview constructs among the low acceptors.

Nature of science PCK coding constructs different among low acceptors. In addition to thinking that theories are speculative, low acceptors had other constructs related to their nature of science PCK. Prior to the training, Julianne’s response to the student saying evolution is “just a theory” was contradictory, showing she did not fully understand what a theory is, and just how robust they are. Julianne would first ask the student to offer his or her own definition of *theory*. While she thinks that a “theory has been something that is proven”, she also thinks that theories are tentative and “will remain a theory until somebody comes back sand says…I’ve found this other information that changes the outcome of what that was” (pre-interview). Julianne’s posttraining nature of science PCK more closely reflects an accurate understanding of the different methods scientists use to answer questions. She thinks that scientists use different methods depending on their question, and recognizes that scientists do not follow a singular, linear scientific method. Instead, she explains,

> I think you’ve got to determine what answers you need first and then you’ve got to decide how you’re going to get to that answer. From what I remember you have a question. You want to answer the question, which kind of is the scientific method, but then how are you going to answer the scientific question. You get side tracked. I didn’t expect to find that so that may develop a new question which leads you on a different course and you may not ever get at that point to your original question. You’ve got to get back to the original one, maybe, maybe not. It depends on whether you found out on where this branch led you. Maybe it dead ends. Maybe it doesn’t. You keep going in that direction and totally forget about your original answer. It all starts with a question you want to answer, but then how you get to the means of the answer may depend on what you use (post-interview).

Teresa’s creationist beliefs are evident in her pretraining nature of science PCK. She accepts that theories are based on observations, but no one has proven the theory to be wrong or right with 100 percent accuracy. Teresa’s posttraining nature of science PCK aligns more closely with scientific understanding when exploring how scientists conduct their research. Teresa recognizes that scientists use different methods depending upon their question. She says scientists may “have a similar line of thinking”, but depending on their research question and scientific discipline, they would “go about solving things differently”. For example, a paleontologist would conduct investigations using fossil evidence, while a cancer researcher may conduct experiments in a lab.

Prior to the training, Joycelyn does not have an accurate understanding of the nature of science, and would reinforce those misconceptions to her students. When asked if evolution is “just a theory”, she would tell the student that it is “just a theory” because humans were not there to observe what happened. Posttraining Joycelyn still retains misconceptions about the nature of science, particularly about how scientists conduct their research using the scientific method. Joycelyn thinks that scientists follow a definite set of steps in performing the scientific method, and that everything in science begins with observing. She used to teach the scientific method in depth, but no longer teaches it as specifically as she used to because she is supposed to integrate the scientific process skills in with the teaching of the content.

Fossil PCK coding constructs consistent among very high acceptors. To explore participants’ PCK about fossils, participants were asked in the pre-interview how they would explain to a student how a fossil got on top of a mountain. This question was used to assess the components of PCK identified by Magnusson et al. (1999) related to knowledge about students’ understanding of the fossil record, and knowledge about instructional strategies for teaching the fossil record. All very high acceptors would explain that the land where the fossil was formed was previously covered with water, and that the earth's surface changed over long periods of time such that the fossil is now on the mountaintop. Both Stan and Annie, the middle school teachers, incorporated plate tectonics into their responses. Stan specifically discussed that two continental plates collided on a convergent boundary, eventually forming mountains where a low-lying area that was covered by the sea once was. Annie emphasized that over time the ocean has covered different parts of the earth, and the low-lying features may have been uplifted over a long period of time to form a mountain range. Tammy introduced the concept at a more introductory level, and emphasized that the earth's surface has changed over periods of time, but did not incorporate plate tectonics into the discussion.

On the post-interview, participants' PCK about fossils was assessed by asking how they would respond to students debating if the fossil record provides evidence for evolution. This interview question was used to assess participants' PCK regarding their knowledge about students' understanding of the fossil record, and their knowledge about instructional strategies for teaching about the fossil record.

While not all high acceptors would respond in the same manner, they would all present that gaps in the fossil record are caused by fossilization bias. Fossilization bias occurs because not all organisms are equally likely to fossilize and those that do become fossils are not equally likely to be found.

Fossil PCK coding constructs different among very high acceptors. While the high acceptors had consistencies in their constructs regarding PCK about fossils, they also had differences in their fossil PCK. Prior to the training, while Annie recognized the fossil most likely got onto the mountaintop due to earth's changes over time, she also said the fossil could have been brought to the mountaintop by another organism, such as a bird or a person.

After the training Annie's fossil PCK continued to align with scientific understanding of the concept. In addition to telling students that the gaps in the fossil record are caused by fossilization bias, she would also emphasize that even with the gaps, the fossil record still provides evidence for evolution. She finds the "whole idea of missing links" to be misleading because there will never be a "100 percent complete record" (post-interview). Instead, she compares reconstructing the fossil record to reconstructing events of the more recent past by telling a student he/she can,

> Go to Rome and you can figure out it's a palace without seeing it rebuilt. You just look at the floor and you can see different pieces of it and you know what's going on. I feel like that's a good analogy for the fossil record. There's little pieces left over and it's enough to say this is probably what happened even if you can't see the whole thing (post-interview).

Annie is aware of multiple examples of transitional fossils she could use as examples to students providing evidence for evolution, including whale and hominid evolution. She would most likely share the evolution of apes with her students as a set of transitional fossils because that is the group with which she is most familiar.

Both Stan's pre- and posttraining fossil PCK aligns with scientific understanding, and he makes multiple connections among scientific topics which can help his students develop a deeper understanding of fossilization. Prior to the training, in addition to incorporating plate tectonics and convergent boundaries into his description of how the fossil most likely got onto the mountaintop, he was the only participant to explain the long length of time required to actually make a fossil. After the training, similarly to Annie, Stan agreed that gaps in the fossil record are caused by fossilization bias, but it still provides evidence for evolution. He explains that because of processes including weathering, plate tectonics, and decomposition very few organisms get fossilized; thus "natural gaps are created" (post-interview). He recognized there are gaps in the rock layers, and there are billions of fossils that will never be found because they are buried in places that are inaccessible. He further explains that "there are tons of things going to that prevent us from often ever seeing transitional forms", but just because there are gaps, it does not mean evolution has not occurred (post-interview). He identifies transitional forms discussed during the training program, such as *Tiktaalik roseae*, that he could share with his students as evidence for evolution in the fossil record, and would suggest they visit the Texas Memorial Museum to view additional fossil evidence supporting evolution. He would explain to his students that the rate of evolution varies; while some transitions occur slowly, other things undergo punctuated equilibrium, which cause rapid transitional events. He would ask the students to reflect upon the chances of finding transitional forms if evolution is occurring at a quick rate.

Both prior to and after instruction, Tammy would not respond to her students in as much depth as the other very high acceptors, and often avoids fully answering her students' questions about evolution. She had no additional pre-instruction fossil PCK constructs for how she would respond to a student questioning how the fossil got to a mountaintop. After instruction, when asked if the fossil record provides evidence for evolution, she would explain there are gaps in the fossil record, but would not discuss why there are gaps because "they don't want us to teach beyond the TEKS" (post-interview).

Fossil PCK coding constructs consistent among moderate acceptors. Moderate acceptors responded similarly to the very high acceptors concerning the pretraining interview question assessing their fossil PCK. All moderate acceptors accurately explained the fossil got on the mountaintop because the land where the fossil was formed was previously covered with water, and the earth's surface changed over long periods of time such that the fossil is now on the mountaintop. While Sonja would provide a general description that earth had changed over time and that a mountain has formed, Tara would discuss the concept to her middle school students in more depth by discussing geological processes such as continental drift. There were no applicable consistent posttraining constructs to moderate acceptors PCK about fossils.

Fossil PCK coding constructs different among moderate acceptors. While there were consistencies among the moderate acceptors in their fossil PCK, there were also differences in their responses. There were no additional constructs for Sonja's pretraining fossil PCK.

Sonja's response to the students' questioning if the fossil record provides evidence for evolution shows she does not have a thorough understanding of why there are gaps in the fossil record. She acknowledges there are gaps in the fossil record, yet does not explain why they are there. She says the evidence for evolution is there, though people will interpret it differently.

Prior to the training, when describing how the fossil got on the mountaintop Tara would provide an explanation about earth's surface changing over time, and then would also show her students or reference actual fossils of ocean organisms that were found on land to reinforce the concept. After the training, Tara would explain to her students that while there are gaps in the fossil record, the fossil record still provides evidence for evolution. Even with the gaps, Tara thinks the fossil record still provides a great timeline of events because we have millions of years of record both before and after any gaps.

Fossil PCK coding constructs consistent among low acceptors. Similarly to both the very high and moderate acceptors, low acceptors accurately responded to the pretraining interview question assessing their PCK by explaining the fossil got on the mountaintop because the land where the fossil was formed was previously covered with water, and the earth's surface changed over long periods of time so that the fossil is now on the mountaintop. There were no applicable consistent posttraining constructs for low acceptors fossil PCK.

Fossil PCK coding constructs different among low acceptors. While there were consistencies among how low acceptors responded to scenarios eliciting their fossil PCK, there were also differences in responses. There we no additional applicable constructs for Julianne's fossil PCK. After instruction, Julianne would tell students questioning if the fossil record provides evidence for evolution that the gaps are caused by fossilization bias, but it still provides evidence for evolution. She identified homologous structures among different species to be one type of evidence for evolution in the fossil record.

There were no additional pretraining constructs for Teresa's fossil PCK. Teresa would tell her students questioning the fossil record that while there are unexplained gaps in the fossil record, it does provide evidence that there has been change through time. She acknowledges that fossil record shows there have been changes in the environments of Texas, such as limestone rock providing evidence for an ocean, but inaccurately thinks that scientists do not know what caused the shifts. She provides the example of the non-avian dinosaur extinction event as an example of a change that scientists cannot explain why the extinction happened.

Pretraining, Joycelyn would explain how the ocean fossil got to the mountain top by also emphasizing that the earth has changed over long periods of time. She would also reference fossils of ocean organisms that have been found in Central Texas. After the training, Joycelyn would emphasize that the gaps in the fossil record are caused by fossilization bias. She incorporated multiple activities from the training to model multiple causes for bias in the fossil record.

Phylogeny PCK coding constructs consistent among very high acceptors. Prior to the training, interviewees' PCK about phylogeny was assessed by having them interpret a great ape cladogram. This interview question was used to elicit participants' PCK related to their knowledge about students' understanding of phylogeny, and their knowledge about instructional strategies for teaching phylogeny. Very high acceptors consistently said that the cladogram showed the relatedness of different species, though they did not all agree with the types of evidence was used to support the cladogram.

After the training, interviewees' PCK about phylogeny was assessed by asking how they would respond to a student who said "I didn't evolve from a monkey" during a class discussion about the great ape cladogram. This interview question was used to elicit the aspects identified by Magnusson et al. (1999) related to participants' PCK associated with their knowledge about students' understanding of phylogeny, and their knowledge about instructional strategies for teaching phylogeny. Very high acceptors consistently responded to the student's statement by explaining that humans and chimpanzees evolved from a common ancestor, not that one evolved from the other. To reinforce the concept with her students Tammy would tell them, "It's not like some great ape just gave birth to a human" (pre-interview). Both Stan and Annie said they frequently have to counter this misconception directly in their teaching. High acceptors also explained that the cladogram shows that great apes and monkeys continue to evolve. Stan provided the most detailed explanation of all of the interviewees by not only thinking of how humans are different from our ancestors, but by getting students to think in terms of how chimpanzees are different from their ancestors and how they have evolved over time.

Phylogeny PCK coding constructs different among very high acceptors. Both prior to and after the training, Annie had a thorough understanding of how to interpret a cladogram, and accurately identified common misconceptions people have when interpreting them. She recognized that the great ape cladogram shows that humans and apes originated from a common ancestor, and that humans are most closely related to chimpanzees and bonobos. She also explained that the relationship of the chimpanzee and bonobo on the cladogram indicate they are closely related. When asked why humans were on the right side of the cladogram, she accurately responded that the nodes are reversible and there is no particular reason the humans are on the right. She thinks that many people would interpret the humans on the right as indicating they are the smartest organisms or the most recently evolved, but that is not the case because humans and chimpanzees have been evolving for the same amount of time since the last common ancestor. After the training, she further explained that the cladogram shows that human's closest living relative is the chimpanzee.

While Stan had a fairly thorough understanding of how to interpret the great ape cladogram prior to the training, the training program helped him deepen his understanding and learn how to teach the concepts more effectively to his students. He recognized the cladogram shows peoples' ancestors were not human, and that speciation events caused the branching of the phylogeny. He explained that evidence from multiple scientific areas supports the hypothesis of when the speciation events took place. He has a partial understanding of the types of evidence used to develop cladograms. He accurately identified genetic evidence as one type, and then also included fossils as another type of evidence. While cladograms can be developed based on fossils, it is actually the morphological characteristics of organisms which is the other type of evidence. He recognizes that humans are on the right of the cladogram for "no particular reason," and that the direction of the cladogram could be reversed without changing the meaning (pre-interview). After the training, Stan still says the evidence for the cladogram is based on genetic evidence, but also mentions morphological characteristics too. He suggests using an activity from the training to teach students the types of evidence used to determine the relationship between humans and chimpanzees. He also began to use more sophisticated vocabulary in describing the cladogram after the training, and referenced different “clades” on the cladogram (post-interview) when talking about different groups.

Prior to the training, Tammy had a moderate understanding of how to interpret a cladogram, though she had some common misconceptions about it as well. She accurately explained that the cladogram shows speciation events, and that evidence for it is based on and/or supported by genetic evidence and morphological characteristics. She also accurately explained that the relationship of the chimpanzee and bonobo on the cladogram indicate they split into two groups. However, Tammy inaccurately interpreted that the humans were on the right of the cladogram because they were the last to evolve. She also explained that the human cladogram is based on limited data. There were no additional posttraining constructs for Tammy’s phylogeny PCK.

Phylogeny PCK coding constructs consistent among moderate acceptors. Similar to the very high acceptors, pretraining, the moderate acceptors consistently said the cladogram showed the relatedness of different species. After the training, the moderate acceptors consistently explained the cladogram shows that humans and chimpanzees evolved from a common ancestor, and the evidence for the cladogram is based on comparing genes and morphological characteristics. The training program impacted both moderate acceptors’ teaching and/or knowledge of phylogeny because both interviewees used activities from the training program with their students and/or referenced training activities to help them formulate their response to the interview question.

Phylogeny PCK coding constructs different among moderate acceptors. Sonja had a moderate understanding of how to interpret a phylogeny prior to the training, and held common misconceptions about creating and interpreting them. She accurately interpreted the cladogram to show that humans and apes originated from a common ancestor, and that humans are most closely related to chimpanzees and bonobos. She explained that the relationship of the chimpanzee and bonobo on the cladogram indicate that they are closely related, and that is based on the fact that they are similar looking. She recognized that the evidence for the cladogram is based on similarities, though she was unable to specify what the similarities were based upon. She also inaccurately interpreted that humans were on the right of the cladogram because they share characteristics with bonobos. Sonja made that interpretation by inaccurately reading the "tips" of the phylogenetic tree in which she saw that the bonobo and human were next to each other. After the training, Sonja had a more accurate understanding of how to interpret a cladogram, and was able to identify the two types of evidence used to create phylogenies – genes and morphological characteristics.

Prior to the training, Tara held several misconceptions about interpreting the great ape cladogram. She recognized that cladograms show relatedness of different species, and thought the evidence for them was based on the behavioral similarities of the species, morphological characteristics, and organ placement within the organisms. She thought that humans were on the right of the cladogram because of both Western reading conventions and because they were the last to evolve. She thinks the relationship of the chimpanzee and bonobo on the cladogram indicate that the bonobo started off as a chimpanzee and then adapted, so that now they are two different species.

Tara had a more accurate understanding of how to interpret the great ape cladogram after the training, and correctly identified the types of evidence scientists use to support the cladogram and what the cladogram actually shows. She also began incorporating activities from the training with her students when teaching about human and chimpanzee relationships.

Phylogeny PCK coding constructs consistent among low acceptors. Prior to the training, low acceptors demonstrated having a partial understanding of phylogeny. The low acceptors agreed with the moderate and very high acceptors that the cladogram shows the relatedness of different species. Low acceptors consistently said the evidence for the cladogram is based on/supported by morphological characteristics of the differing organisms represented on the cladogram, but did not reference genetic evidence. They also consistently said the relationship of the chimpanzee and bonobo on the cladogram indicates they are closely related. There were no consistent posttraining constructs among the low acceptors to how they would respond to a student who said “I didn’t evolve from a monkey” during a class discussion about the great ape cladogram.

Phylogeny PCK coding constructs different among low acceptors. While prior to the training Julianne accurately interpreted the cladogram to show the relationship of different species, she also had several misconceptions about how to interpret it. She said the evidence for the cladogram is based on and/or supported by the behavior of the different species and the placement of the organs within their bodies. She explained that humans are on the right of the cladogram because they were the last to evolve.

Julianne had a more accurate understanding of the great ape cladogram after the training. She explained that the cladogram shows that humans and apes originated from a common ancestor, and that evidence for the cladogram is based on genetics.

Prior to the training Teresa would approach teaching the cladogram by helping her students learn how to interpret it from a scientific perspective, and then would critique it through a creationist perspective by asking the student to reflect on “Where in the Bible does it say Adam was created from an animal?” (pre-interview). While Teresa accurately interpreted the cladogram to show that humans and apes originated from a common ancestor, she also has some misconceptions about interpreting cladograms. She thinks that the evidence for the cladogram is based on and/or supported by morphological characteristics, the behavior of the different species, and whether the species are social or not. She does not know why the humans are on the right of the cladogram.

After the training Teresa had a more thorough understanding of how to interpret a cladogram, though she would still present the teaching of it through a creationist perspective. She accurately interpreted the cladogram to show the relatedness of different species, and that is based shared on morphological characteristics. Teresa explains that from her perspective humans and chimpanzees have shared morphological characteristics because God made us that way, and would tell her students, “The Bible teaches us that we’re the only ones made in his image. While we can share these characteristics in common, we’re definitely set apart” (post-interview). Teresa is particularly appreciative that the training reinforced her conception that people are “no better” than other animals because a substantial part of her teaching focuses on the idea that people “have been given dominion over creation, but that means we are supposed to take care of it” (post-interview).

Joycelyn had a limited understanding of how to interpret the great ape cladogram, and held several misconceptions about phylogeny prior to the training. While she accurately interpreted the cladogram to show the relatedness of different species, she did not accurately understand the details of how to read the tree. She thought the relationship of the chimpanzee and bonobo on the cladogram indicates that the bonobo branched off the chimpanzee lineage and that the bonobo was more recently discovered. When interpreting the cladogram she read the “tips” of the tree instead of the nodes when she inaccurately thought that humans were on the right because they share characteristics with bonobos.

After the training Joycelyn had a more accurate understanding of phylogeny and explained that the cladogram shows that humans and chimpanzees evolved from a common ancestor. She would not present the topic in much more depth than that to her 5th grade students because she thinks additional information may "be over their heads at this age" (post-interview), though she could anticipate using an activity from the training comparing the morphological characteristics of humans and chimpanzees.

Deep Time PCK coding constructs consistent among very high acceptors. To assess participants' pretraining deep time PCK, interviewees were asked to identify the challenges associated with teaching deep time, and describe how they would teach the concept. This interview question was used to elicit components identified by Magnusson et al. (1999) of PCK including: knowledge about science curriculum related to deep time, knowledge about students' understanding of deep time, and knowledge of instructional strategies for teaching deep time. Very high acceptors consistently identified that deep time was conceptually challenging because students do not understand long lengths of time.

Participants' posttraining deep time PCK was assessed by asking them to describe a lesson in which they could help students develop an understanding of the sequence of events occurring throughout deep time. This question was used to elicit components of PCK including: knowledge about science curriculum related to deep time, knowledge about students' understanding of deep time, and knowledge of instructional strategies for teaching deep time. All very high acceptors reported they would use a geological timeline activity they participated in during the *Life Through Time* training to teach the concept to their students. During the geological timeline activity, students first had to predict when along a timeline they think major geological and evolutionary events occurred. Students then participated in inquiry- and specimen-based activities investigating the major evolutionary and geological events that happened during major time periods. Finally, the students returned to the original timeline and revised their events predictions to reflect their revised understanding of events throughout time.

Deep Time PCK coding constructs different among very high acceptors. Though there were consistencies among responses for the very high acceptors in their deep time PCK, there were also differences among their responses. Prior to the training, Annie identified an additional challenge associated with teaching deep time was that her students do not have the mathematics skills needed to understand geological time. Specific challenges Annie identified include lack of understanding of scientific notation, decimals, and exponents. Both before and after the training, Annie used different timeline analogies to teach her students about deep time. In one analogy, she compared all of earth's history to the 24 hours on a clock, and emphasized that human kind and written history have only been in existence for a "fraction of the last second" (pre-interview). Through using the clock analogy Annie perceived her students "really do get the picture, a little bit, at least that time is much bigger than you can conceptualize as a human being who lives only 100 years" (pre-interview).

Prior to the training, although Stan recognized his students have trouble understanding deep time because they do not understand long lengths of time, he admits he does not concentrate on teaching students about deep time. While he focuses on using scale with distances when teaching astronomy concepts, he thinks he should help students "understand how long a million is in terms of time" (pre-interview). After the training, Stan had an increased deep time PCK and plans on using the geological timeline activity from the training to teach the concept to his students. He even made recommendations about how to improve the activity to make it more effective at teaching the intended concepts.

Pretraining, Tammy identified students' lack of knowledge of ancient organisms to be an additional challenge to teaching deep time. Though she has taught her students about relative dating based on stratigraphy and where fossils are found, she questions how deeply her students understand the concept because they are unfamiliar with "the creatures that lived long ago" (pre-interview). She teaches her students about stratigraphic principles using a simulation exercise incorporating concepts including erosion, deposition, and fossilization, but they "just need to know the bottom layer's the oldest and the top layer is the youngest" (pre-interview).

After the training, Tammy explains she does not cover deep time in depth because the TEKS do not require it; instead, she primarily emphasizes that the ordering of the rock layers in which a fossil is found determines its relative age. While she says she does not teaching deep time extensively, Tammy actually integrated several of the training activities emphasizing a thorough examination of deep time into her curriculum, including stratigraphic layer modeling kits and the ordering of geological events timeline activity. Through the stratigraphic layer modeling kits, students explore three-dimensional cross sections of the earth that contained both rocks and fossils. They infer what the environment was like at each different rock layer, based on the rocks and fossils present, and use relative dating methods to find approximate ages for the fossils. To help make deep time more relevant to her students' lives Tammy would have her students create a timeline of their lives and then relate that to that fact that all past events have a sequence. She would also make connections to timelines in social studies and historical events.

Deep Time PCK coding constructs consistent among moderate acceptors. Prior to the training, similar to the very high acceptors, moderate acceptors also consistently identified that deep time was conceptually challenging because students do not understand long lengths of time. On the posttraining deep time PCK assessment, all moderate acceptors reported they would use an activity from the *Life Through Time* training to teach the concept to their students. Sonja said she would use the same geological timeline activity the high acceptors referenced, and Tara would use a stratigraphic layer modeling kit.

Deep Time PCK coding constructs different among moderate acceptors. Though there were consistencies among responses for the moderate acceptors in their deep time PCK, there were also differences among their responses. Pretraining, Sonja said that her students' limited life experiences make it challenging for them to understand deep time. Her students do not travel much outside of their city, so they have not seen or experienced different landforms, climates, or environments. She would use visuals and graphic organizers "as much as possible because they need to see it" (pre-interview) to help her students understand concepts related to deep time. In her presentation she would emphasize that past events shape landform changes, and those changes happen very slowly.

The training helped Sonja gain understanding into when major evolutionary and geological events took place because prior to it she had no "clue when life or creatures or organisms appeared" (posttraining). She would use the same geological timeline activity she participated in during the training with her students to emphasize relative dating and sequencing of major evolutionary events.

Though Tara is responsible for teaching TEKS related to plate tectonics, prior to the training she does not feel she teaches concepts related to time in depth. She does not cover time in depth because the concept of time is not tested on the state-mandated standardized test so she may introduce it, but then "moves on to other things" (pre-interview). When she does introduce time, she thinks the best way to do so is through topographic maps to show how landforms have changed through time. After the training, Tara would present deep time in much more depth than prior to the training. She would use the stratigraphic layer modeling kit from the training to explore concepts including: the law of superposition, relative dating, and reconstructing paleo-environments based on the rock and fossil evidence found in each layer.

Deep Time PCK coding constructs consistent among low acceptors. Prior to the training, there were no consistent deep time PCK constructs among the low acceptors. However, on the posttraining deep time PCK assessment, all low acceptors reported they used an activity from the *Life Through Time* training to teach the concept to their students. Julianne and Joycelyn used a geological timeline activity, and Joycelyn and Teresa used a stratigraphic layer modeling kit.

Deep Time PCK coding constructs different among low acceptors. Though there were consistencies among responses for the low acceptors in their deep time PCK, there were also differences among their responses. Prior to the training, Julianne identified two conceptual challenges to understanding deep time: students do not have a concept of large numbers and scale, and the events happened before they were born. Julianne recognizes her students have a hard time grasping large numbers, and is aware of a picture book that she can read to students to help them gain a better understanding of large numbers. Though she has not read the book to her students before, she planned on using the book when introducing geological time.

After the training, though Julianne no longer teaches science, she identified the geological timeline activity from the training to be an activity she would use if she had an opportunity to teach about deep time again. She also provided feedback about how she would modify the activity to help her students develop conceptual understanding, including making the scale of the timeline more clear.

Prior to the training, Teresa's creationist perspective is evident in her deep time PCK. The primary challenge she has in the teaching of deep time is that she questions the validity of radiometric dating, which is a common, yet inaccurate, argument anti-evolutionists use against the validity of evolutionary theory. Teresa questions "the actual dating of the rock itself and the fault within carbon dating" (pre-interview). While she believes radioactive decay occurs, she has "problems sticking actual numbers to them…because there's so much left to question about the actual dating of it" (pre-interview). Thus, when teaching her students about absolute dating she presents the concept through the creationist perspective by explaining the ages are "scientists' best estimates of what they think the age is, but no one really knows beyond a reasonable doubt" (pre-interview).

After the training, Teresa still teaches deep time through a creationist perspective, though she uses the stratigraphic layer models from the training to teach her students the sequence of events that have occurred throughout geological time. She uses the models "all the time" because they are the "most effective" tool she has to teach her students about reconstructing paleo-environments based on the rock and fossil record (post-interview).

Before the training, Joycelyn explained that deep time is challenging to teach because students do not understand long lengths of time, and "for something to be older than their mother or grandmother is more than they can fathom" (pre-interview). When teaching deep time, she taught it in isolation from other scientific disciplines and primarily focused on basic stratigraphic principles.

The training had a substantial impact on Joycelyn's deep time PCK, and afterwards, she taught it in much more depth and breadth than she had previously. While using the stratigraphic layer modeling kit and geological timeline activities to cover stratigraphic principles, she also integrates additional key concepts in the earth and life sciences, as well as language arts. These include animal adaptations, sequencing of major evolutionary and geological events throughout time, and reconstructing paleo-environments based on rock and fossil evidence.

Speciation PCK coding constructs consistent among very high acceptors. To assess participants' pretraining PCK about speciation, interviewees were asked to describe a lesson in which they could help their students understand how the different species of Galapagos finches could have evolved from a single ancestor. This interview question was used to elicit the following components identified by Magnusson et al. (1999) of PCK: knowledge about science curriculum related to speciation, knowledge about students' understanding of speciation, and knowledge of instructional strategies for teaching about speciation. There were no consistent constructs among the very high acceptors about how they would respond to the question.

To assess participants' posttraining PCK about speciation, interviewees were asked to describe a lesson in which they could teach how speciation by geographic isolation occurs. This interview question was used to elicit components identified of PCK including: knowledge about science curriculum related to speciation, knowledge about students' understanding of speciation, and knowledge of instructional strategies for teaching speciation. All very high acceptors consistently described a lesson in which the speciation occurred because of geographic isolation, as opposed to another process.

Speciation PCK coding constructs different among very high acceptors. While prior to the training Annie correctly identified speciation via geographic isolation as the main concept driving the evolution of the Galapagos finches, she introduced a common misconception into her description of the methods she would use to teach how the process happened. Annie began her explanation by saying that when food is plentiful the birds could have eaten whatever they wanted; however, when there is a food shortage a "bird with a certain beak would eat a certain food source" and would become "the specialist in the food source" (pre-interview). Over time those birds went through "some sort of reproductive isolation" and moved to different islands, and are then called a different species. While Annie understands the main points behind speciation, her description in how birds can become food specialists could reinforce a common misconception that that organisms can adapt because they need to; instead, Annie should have incorporated the process of natural selection into the lesson.

After the training, Annie accurately identified both a lesson from the training and a non-training one that could be used to teach how speciation via geographic isolation occurred, though she still did not integrate the process of natural selection into her description of how the isolated populations could actually split into two different species.

Both before and after the training, Stan has a thorough understanding of speciation via geographic isolation and how to teach it. He teaches the concept to his students by integrating multiple concepts in earth and life sciences including: adaptations, plate tectonics, species concepts, and natural selection. In the activity, he first has his students identify adaptations for both warm and cold weather. He then introduces a scenario in which rabbits are on an island, which, through plate tectonics, splits in half and divides the rabbit population into two separate ones. The two separate islands are drifting in opposite directions – one towards the equator and one towards the North Pole. Students are then asked to predict what the two separate populations will look like over time through natural selection, and if they think the two populations would be able to mate if they were reintroduced. After the training Stan said he could also introduce speciation through an activity he participated in from the training program, and made suggestions about how he thought the activity could be modified to make it more effective.

Prior to the training, Tammy did not understand that the emphasis of the evolution of the Galapagos finches was by speciation via geographic isolation; instead the lesson she described emphasized the relationship between the finches' bill structure and how that relates to what they can eat. While she would explore the relationship between different vegetation on the islands and the types of finches there are, she would not discuss the topic with her students in any further depth, particularly how the different finches evolved from an original ancestor because she perceives that to be too complex for her 5th grade students. Tammy questions how deep the TEKS require her to teach about the Galapagos finches and Darwin's voyage on the HMS Beagle. She says she mentions it to her elementary students because she wants them to be prepared for when they hear it again in middle and high school.

Posttraining, Tammy continued to describe a lesson emphasizing the relationship between birds' bills and what they can eat, instead of speciation via geographic isolation. During the lesson she described Darwin's voyage to the Galapagos Islands, and says he found different species of birds that are related, but are different. She then shows the students pictures of different types of bills from birds including a toucan, finch, and an eagle. The students try to pick up different kinds of food with tools that are meant to represent the different birds in the pictures.

Speciation PCK coding constructs consistent among moderate acceptors. Moderate acceptors' pretraining speciation PCK did not align with scientific understanding of speciation. In describing how the different species of finches could have evolved from one ancestor, they consistently identified and emphasized different selective pressures driving natural selection of species, as opposed to speciation via geographic isolation. For example, Tara thought the speciation occurred because “it has something to do with the type of food they had to eat, or the type of climate they lived in, or the environment they had to live in” (pre-interview). Sonja would explore how species are different because of where they live, such as birds that need a lot of water to survive live in wetter areas, while birds that do not need much water live in arid areas. While the teachers explained multiple factors that may have caused the varying species of finches to have different adaptations, their descriptions did not include information about how this diversification could have occurred. To demonstrate they had scientifically-aligned understanding, teachers’ descriptions should have included concepts such as the division of one population of organisms into two or more populations, geographical isolation of the populations, and natural selection. There were no consistent posttraining constructs for moderate acceptors speciation PCK.

Speciation PCK coding constructs different among moderate acceptors. There were no additional pretraining constructs for Sonja’s speciation PCK. Posttraining, Sonja had a cursory understanding of speciation. While she is aware of examples she could use to teach speciation to her students, she does not understand the details of the examples and/or that they contain misconceptions. For example, she provided the “squirrels on the north rim and south rim of the Grand Canyon” as an example of speciation by geographic isolation. She says the two species of squirrels came from a common ancestor, but are different because of the climate variations between the north and south rim of the canyon. After further probing, Sonja questions if the squirrels even exist because she may have just learned about them in a movie. While Sonja is accurate that there are two different species of squirrels on the different rims of the Grand Canyon that provide an example of speciation via geographic isolation, she inaccurately described the climate differences to be the isolating factor, instead of geographic isolation.

Prior to instruction, Tara did not have an accurate understanding of how the Galapagos finches could have evolved over time, and the methods she would use to teach the concept would reinforce students' misconceptions that organisms can adapt because they need to do so. Tara would teach her students about finch evolution through an adaptation game in which they could role a dice and "something would happen to them" so they would "have to adapt" based on the role of the dice. They would go through several rounds and at the end they could see that people became different types of species. While she was not familiar with the details of the evolution of the finches, she thought the driving factor was based on limited natural resources or food choice affecting what the birds eat, and thus, their survival. Post instruction, Tara accurately identified two different activities from the training session she could use to teach speciation via geographic isolation, and suggested ways in which she could modify one of the lessons for use in her class.

Speciation PCK coding constructs consistent among low acceptors. Similarly to the moderate acceptors, low acceptors pretraining speciation PCK did not align with scientific understanding of speciation. Instead of emphasizing speciation via geographic isolation, low acceptors consistently emphasized in their finch evolution lesson that limited natural resources or food choice affects what finches eat. Julianne inaccurately explains that as vegetation on one island evolved then the finch "had to change what it ate" (pre-interview). According to Joycelyn, the finches evolved because their food source was not readily available, and they had to try another food to survive. She explained, "The ones that tried the right food lived and the others ones died" (pre-interview). Teresa said that if one species of finch traveled to another island with a different food source, then the bird would adapt to eating the new food source, and that adaptation would become predominate in the population.

Low acceptors posttraining PCK was more closely aligned with scientific understanding of speciation. All low acceptors consistently described a lesson in which they emphasized speciation occurring because of geographic isolation. Additionally, they all would approach teaching the concept using a simulation they participated in during the training program.

Speciation PCK coding constructs different among low acceptors. There were no additional pre- or posttraining speciation PCK constructs for either Julianne or Joycelyn.

Prior to the training, in teaching about the evolution of the Galapagos finches, Teresa would also be sure to emphasize the creationist belief that species can change within their kind, but that they do not evolve into different organisms. For example, she would present that the Galapagos finches changed into other birds, but they cannot change into a fish. After the training, Teresa would teach speciation by geographic isolation using a simulation from the training, and would emphasize differential survival based on limited resources. She thought the simulation was particularly effective because it could be used to model the drought conditions that Texas is currently experiencing.

Summary for macroevolution PCK. While there were many consistencies in acceptance group members' macroevolution PCK, there were also many differences both among group members and between acceptance groups. Prior to instruction, all very high acceptors had a more scientifically aligned nature of science PCK than the moderate and low acceptors. The very high acceptors were the only acceptance group that consistently reported that theories are based on evidence. Both the moderate and low acceptors did not perceive theories to be robust. Instead they thought theories are speculative and subject to change with relative ease.

After instruction, there were no consistencies among the acceptance groups about their perception that there is a singular "scientific method" that all scientists follow. While one teacher from each acceptance group thought that there is a definite set of steps all scientists follow, called the scientific method, at least one teacher per acceptance group thinks that scientists all use different methods depending on their question. The participants that perceive the scientific method to be a single, linear, multiple step procedure presented that misconception to their students by teaching experimental design as the only type of scientific investigation.

Prior to instruction, all participants were able to accurately explain how a fossil of an ocean organism could be found on top of a mountain. The middle school teachers in the very high and moderate acceptance groups provided a more detailed explanation of the geological processes responsible for changing earth's surface over time than the elementary teachers.

After instruction, while participants had varying amounts of fossil PCK, they all accurately explained that gaps in the fossil record were caused by fossilization bias. Two of the very high acceptors discussed specific transitional fossils that can be used to document how the fossil record provides evidence for evolution. While all participants recognized there were gaps in the fossil record, at least one participant in the very high and low acceptance group avoided directly addressing whether the fossil record provided evidence for evolution.

All participants had at least a limited phylogeny PCK prior to the training. Pretraining, all participants accurately explained that the great ape cladogram shows the relatedness of different species. The very high acceptance group had the most scientifically aligned phylogeny PCK, though Tammy had several misconceptions about how to interpret the cladogram. Each member of the moderate and low acceptance groups had misconceptions about interpreting the great ape cladogram, such as humans are the most recently evolved of all of the species and that phylogenetic relationships are based on the behavior of species.

After the training, all participants' phylogeny PCK improved. The majority of participants would explain to students that the cladogram showed that humans and chimpanzees evolved from a common ancestor, as opposed to evolving from one another. All participants also accurately identified at least one of the two different types of evidence used to create a phylogenetic tree – genetics and/or morphological characteristics. After the training the very high acceptors were the only group of teachers that explained that the great apes and monkeys continue to evolve. Both of the moderate acceptors used or referenced materials from the training series to teach the concepts to their students. Teresa would emphasize the creationist perspective through teaching about the relationships of the great apes.

Prior to the training, all participants identified conceptual challenges, such as understanding long lengths of time and large numbers, to be particularly difficult to the teaching of deep time. None of the interviewees taught deep time in depth to their students. However, after the training all of the participants planned on or already had incorporated activities from the training program into their curriculum to teach concepts related to deep time. The activities they described incorporating would teach deep time in depth because they span multiple class periods, and use an integrated earth and life sciences approach.

The majority of the interviewees had a limited speciation PCK prior to the training. Two of the very high acceptors, Annie and Stan, were the only two participants who could correctly identify a lesson that could explain how the Galapagos Island finches evolved via speciation by geographic isolation. None of the other participants recognized the process was by speciation; instead they identified factors such as the environment shaping the birds' adaptations, or the birds adapting because they need to, as the factors driving finch evolution. After the training, the majority of participants were able to accurately identify an activity they could use to teach speciation via geographical isolation to their students, and many of them suggested using an activity they participated in during the training.

Chapter Five: Discussion and Implications

This study sought to explore the effects of a sustained teacher training program on 4th through 8th grade teachers' understanding and acceptance of evolution. It also sought to explore the impacts of the training program on teachers' approach to teaching evolution, awareness of challenges related to the teaching of evolution, and PCK about macroevolution. The research questions that guided this study are:

1. What is the effect of participating in a sustained professional development program on 4th through 8th grade teachers' understanding of macroevolution, particularly deep time, phylogenetics, speciation, fossils, and the nature of science?
2. What is the effect of participating in a sustained professional development program on 4th through 8th grade teachers' acceptance of evolution?
3. What's the relationship between 4th through 8^{th} grade teachers' understanding of macroevolution and their acceptance of evolution?
4. How is 4th through 8th grade teachers' understanding of macroevolution related across three time points?
5. How is 4th through 8th grade teachers' acceptance of evolutionary theory related across three time points?
6. What is the effect of understanding of macroevolution on acceptance of evolutionary theory and the effect of acceptance of evolutionary theory on understanding of macroevolution across time?
7. What is the effect of a professional development series on teachers with varying levels of acceptance of evolutionary theory approach to teaching

evolution in schools, awareness of challenges to teaching evolution, and pedagogical content knowledge about teaching macroevolution?

An overview of the significant findings will be presented, followed by the theoretical implications of the research, the limitations of the current study, suggestions for further research, and practical implications of the research.

Significant Findings

Teachers' knowledge and acceptance of evolutionary theory. Teachers' perceptions of the importance of evolution are a key predictor in their approach to teaching evolutionary theory (Deniz et al., 2008). Multiple factors, including teachers' scientific subject matter preparation (Pajares, 1992), acceptance of evolution (Rutledge & Mitchell, 2002), and negative perceptions about evolution (Griffith & Brem, 2004), impact how they teach it.

The *Life Through Time* teacher training program had an impact on two primary factors related to how evolution is taught in schools – participants' knowledge of macroevolution and their acceptance of evolutionary theory. After participating in the entire professional development series, teachers had a significant increase in their understanding of macroevolution and were significantly more accepting of evolution. Consistent with Rutledge and Warden's (2000) findings, there was a significant, positive relationship between teachers' understanding of macroevolution and acceptance of evolution across time points; thus, teachers with an increased understanding of macroevolution tended to be more accepting of evolution. While participants' overall understanding of macroevolution improved as a result of attending the training, similar to other studies based on the conceptual change theory, misconceptions still persisted, particularly about concepts related to the nature of science (Anderson, 1990; Nadelson, 2009; Settlage, 1994).

In exploring the differences among the varying acceptance group levels, the participants in the very high acceptance group were the only participants that had college degrees in a science-related field. They also had taken substantially more college-level science classes than participants in the other acceptance groups, and scored higher on the pretest MUM than those in other acceptance groups. Thus, similar to the findings of Pajares (1992), the more subject matter preparation the teachers had the more likely they were to accept evolution.

All of the very high acceptors had a more scientifically-aligned understanding of evolution and higher acceptance of evolution than the other acceptance groups. However, Annie and Stan, both middle school teachers, who took substantially more college science classes than the other participants and were the only participants certified to teach high school science, had a much more thorough understanding of the nature of science than the other participants. They were the only participants that clearly differentiated between science and religion as different ways of viewing the world in their teaching.

In contrast, prior to the training, the low and moderate acceptors, who had taken the least amount of college hours in science, did not have a fully developed understanding of the nature of science. For example, they did not understand the robustness of a theory, that theories are based on multiple lines of evidence, and did not understand the types of questions science can and cannot answer. In teaching scientific concepts related to the nature of science they likely passed these misconceptions on to their students, or reinforced their students' own misconceptions about the nature of science. The two interviewees who had taken some of the fewest number of hours of college level science were removed from teaching science prior to the completion of the study because of their students' low performance on the 5th grade state-mandated science standardized assessment. One of these teachers, Sonja, had only 12 college level science credit hours, and consistently reported feeling underprepared to teach science.

After the training, while the low and moderate acceptors had a more thorough understanding of the nature of science, misconceptions still persisted. These results are consistent with Nadelson's (2009) findings that even after direct instruction in the nature of science, teachers still retain misconceptions. A potential explanation for the lack of full understanding of the nature of science, even after instruction, is that developing full understanding is a developmental process and participants need extended exposure to evolutionary concepts and the nature of science, even beyond what the professional development series provided (Settlage, 1994).

Prior to the training, the results of this study are somewhat consistent with the findings of Pajares (1992) that teachers with increased subject matter preparation are more likely to teach evolution. The results are also somewhat consistent with the findings of Rutledge and Mitchell (2002) that there are significant associations between acceptance of evolution and classroom time devoted to it. Pretraining, the two very high acceptors who had the greatest number of college coursework in science incorporated evolution concepts whenever possible into their curriculum. However, Teresa, one of the low acceptors who had substantially less college level subject matter coursework in science, introduced evolution concepts at an earlier level and at a greater breadth than all the other participants. While Teresa introduced evolution concepts earlier than all other teachers, it is important to note that before and after the training she did so through a creationist perspective.

After attending the training program, the low and moderate acceptors accepted evolution at significantly higher levels and understood significantly more about macroevolution. Additionally, all of the low and moderate acceptors who were still teaching science at the end of the training reported teaching evolution concepts at a greater depth and breadth than they had before attending the training. Thus, consistent with Rutledge and Warden's (2000) findings, as participants' understanding and acceptance of evolution increased, they were more likely to teach the concepts to their students.

All of the interviewees believed in at least some portion of evolutionary theory. This contrasts with Blank and Anderson's (1997) study in which more than half of the preservice elementary teachers and less than half of the preservice secondary teachers surveyed did not believe in the theory of evolution. The two low acceptors who did not believe all parts of evolutionary theory believed in microevolution, but not macroevolution. This further supports Alters and Alters' (2001) conclusion that there are differing levels of acceptance of evolution, depending upon the scale at which it is presented. Consistent with Blank and Anderson's (1997) findings, prior to the training the interviewees who taught at the middle school level were generally more supportive of evolutionary theory than the elementary teachers.

Consistent with Moore's (2004) findings, prior to the training, all of the low acceptors directly incorporated creationist concepts into their teaching. These results support Nadelson's (2009) study in which teachers holding religions explanations they perceived to conflict with evolution interfered with their ability to teach evolution in compliance with the state science standards. Low acceptors' pretraining teaching did not comply with the teaching of the TEKS because they introduced non-scientific reasoning and religious concepts into the science classroom. After the training, Teresa, who taught at both the elementary and middle school levels, was the only interviewee who said she would continue to teach evolutionary concepts through a creationist perspective. Teresa's insistence on teaching evolution through a creationist lens may have a long term impact on her students' acceptance of evolution. This is the case because resistance to scientific claims persists into adulthood if those claims are contested in society, and if non-scientific alternatives, like creationism, are advocated for by people we find to be reliable and trustworthy, such as teachers (Bloom & Weisberg, 2007).

Previous research studies exploring the relationship between knowledge of and acceptance or belief in evolution have been mixed (Bishop & Anderson, 1990; Demastes-Southerland et al., 1995; Lawson & Worsnop, 1992; Smith, 1994). In contrast to Demastes-Southerland et al.'s (1995) findings that instruction in evolution does not provoke a detectable change in students' acceptance of evolution, the results of this study indicate that professional development in evolution impacts both participants' knowledge and acceptance of evolution.

Participants' prior understanding of macroevolution was a positive predictor in their subsequent acceptance of evolution. This suggests that as understanding of macroevolution evolution increases, participants show a more favorable disposition towards acceptance of evolution. On the other hand, while participants' pretest acceptance of evolution was not a significant predictor for their understanding of evolution at the midpoint of the training, their acceptance of evolution at the midpoint was a significant predictor of their end of training understanding of macroevolution. The results suggest that as teachers participate in more of the training series and have an increased acceptance of evolution, they are more likely to understand macroevolution.

Thus, in contrast to Smith (1994) who holds that lack of acceptance of evolution serves as a barrier to developing understanding, and Lawson and Worsnop (1992) who found that knowledge serves as a barrier to developing acceptance, the results of this study suggest there exists an interplay between both acceptance and understanding, and that deficiencies in either one does not necessarily serve as a barrier to an increase in the other. These results are consistent with Nadelson and Southerland's (2010) findings that the interplay of understanding and acceptance makes the difficulties in teaching and learning about evolution more evident.

Teaching evolution at the elementary and middle school levels. While the NSES, NGSS, and TEKS include concepts related to evolution to be taught to students in 4th through 8th grades, none of the standards directly introduces the term *evolution* until students enter the 6th grade at the earliest, and most typically at the high school level. The NGSS introduce the term *evolution* beginning in the 6th grade while both the NSES and TEKS delay introduction of the term until the high school level.

All of the interviewees reported using the TEKS to decide what science concepts to teach. Teachers in each of the different acceptance level groups questioned if and how the TEKS required them to teach evolutionary concepts. For example, after the training Tara did not feel the TEKS required teaching from an evolutionary perspective but included evolution concepts into her curriculum because the training prepared her to do so. Tammy frequently questioned how she was supposed to present evolution because the TEKS were not clear about specifying exactly what examples she should incorporate into her teaching. Prior to the training several of the elementary teachers — Joycelyn, Julianne, and Sonja — did not think they really taught concepts related to evolution. These results are consistent with Ashgar et al.'s (2007) findings that elementary teachers frequently report that they do not cover or poorly cover evolution concepts in their teaching.

Consistent with Wagler's (2013) critique of both the NSES and NGSS, since the elementary and middle school level TEKS do not explicitly reference evolution, it is up to individual teachers to decide if and how they will introduce evolution in Texas. While all of the interview participants taught evolutionary concepts to their students, many of them, particularly the elementary teachers, did not explicitly introduce the notion of evolution into their teaching. Avoiding introducing evolutionary concepts until students are in high school can have negative consequences, particularly as students, even in elementary school, are aware of the perceived evolution and religion controversy (Donnelly et al., 2008). Students' primary source of resistance to evolution is related to what they know before they are exposed to the science (Bloom & Weisberg, 2007), which presumably is in the form of creationism. Furthermore, depending upon kindergarten through 8th grade teachers' teaching practices, the first and only time Texas students may learn about biological evolution is during a one to ten day unit on evolution in their high school biology courses. Waiting to introduce evolution until students are in high school may further impede students' understanding of it since evolution requires substantial background knowledge to comprehend (Wagler, 2012).

While Evans (2008) found that students can begin reasoning in evolutionary terms when they are about 8 years old, prior to the training, almost half of interviewees perceived concepts related to evolution to be too challenging or abstract for their students to understand. After the training the interviewee participants reported teaching evolutionary concepts in more depth and breadth than they had previously. While the teachers did not report any evaluation data about the effectiveness of their lessons with their students back to me, the majority of the teachers informally said their students were able to understand the concepts presented.

Teachers worry about the perceived negative impacts of evolution and may experience measurable levels of stress even when thinking about teaching evolutionary theory (Griffith & Brem, 2004). This stress may reduce their ability to teach evolution. Consistent with Griffith and Brem's (2004) findings, many of the interviewees felt stressed when teaching about evolution, and would respond to that stress in ways which students' may perceive to be questioning the validity of evolutionary theory. For example, Annie directly told her students they do not have to believe in evolution, which may reinforce the misconception that science is about believing, rather than it being based on evidence.

After the training, many of the participants who were concerned about teaching evolutionary theory had a more thorough understanding of the nature of science, particularly the differences between science and religion. They would differentiate between the two when handling the potentially stressful situation in which a parent and/or student resistant to evolution questioned how they would teach the concept. By differentiating between the two, the teachers reinforced the idea that people can both accept evolution and believe in a higher power; the two are not mutually exclusive.

Counter to van Dijk's (2009) study in which high school teachers primarily taught concepts related to microevolutionary processes, such as mutation and selection, as opposed to macroevolutionary concepts, the majority of the elementary and middle school interviewees reported teaching more macroevolutionary concepts including fossilization processes, speciation, and deep time.

This teacher training program had the greatest impact on the macroevolutionary PCK of the teachers with the least amount of college level coursework in science – the moderate and low acceptors. For example, prior to the training, all of the low acceptors reported they did not cover or avoided teaching parts of evolution, and they incorporated creationism into their science curriculum. However, afterwards the low acceptors incorporated more of the project activities — including a field trip to the Texas Memorial Museum, inviting project scientists to conduct presentations in their classes, use of loaner kit materials, and project curriculum — than the participants from the other acceptance groups. Additionally, two of the three low acceptors reported they no longer teach creationist concepts in their classrooms. Participants in the low acceptance group reported the training increased their strength of understanding of evolution, their confidence in teaching evolutionary concepts, and their approach of teaching science concepts by teaching for breadth and depth by integrating multiple scientific disciplines.

Additionally, prior to the training, neither of the moderate acceptors perceived science to be as important as other subject areas, and focused their teaching on preparing students for the standardized science assessment. After attending the training, Tara, the moderate acceptor who was still teaching science upon completion of the program, reported the training impacted her knowledge of the interrelationship between the life and earth sciences. Furthermore, it helped her teach plate tectonics using an integrated approach, and in more depth than she had prior to the training. This finding suggests that sustained professional development programs such as this one can be valuable tools used to increase in-service teachers' PCK about macroevolution, particularly those teachers who have little college level science coursework and/or those who are not highly accepting of evolution.

Theoretical Implications

On the basis of these findings, as participants' content knowledge about macroevolution and acceptance of evolution increased, the teachers were more likely to teach macroevolutionary concepts. The training particularly impacted the low and moderate evolution acceptors' understanding and acceptance of evolution. In light of these findings, it is important to revisit the theoretical model this study is based upon, the Cognitive Reconstruction of Knowledge Model (Dole & Sinatra, 1998). The CRKM is useful in investigating how people develop understanding and/or acceptance of evolution because many complex factors contribute to peoples' understanding of the concept. This study's results offer continued support for the CRKM as model for the conceptual change process.

Learning is a complex interaction among a person's pre-existing knowledge and motivation for learning new information, the instructional message being presented, and how engaged the person is with the information being presented. The professional development series was developed based on multiple aspects of the CRKM that increase the likelihood of promoting conceptual change including: 1. participants were motivated to learn about evolution as demonstrated in the time commitment they were willing to spend on project activities; 2. the social context, including the facilitators and the program participants, was supportive of learning about evolution; 3. the series was structured to help the teachers understand the relevance of the session content to their individual teaching situations; 4. the evolution concepts were presented in a positive manner and through differentiating between science and religion as different ways of knowing; 5. the concepts were presented at a comprehensible level and by providing background information for concepts that may be more challenging to understand; and 6. project activities were structured to encourage participants to be highly metacognitively engaged. Findings from the study revealed that the sustained professional development program based on the CRKM did promote conceptual change in teachers' knowledge and acceptance of evolution.

Participants in the varying acceptance groups underwent different levels of conceptual change with regards to their understanding of macroevolution or acceptance of evolution. Consistent with Dole and Sinatra's (1998) description of the CRKM, the different levels of conceptual change included strong change, weak change, or no change. As this study was not intended to quantify the amount or type of conceptual change teachers underwent, the different levels of conceptual change that the participating teachers experienced will be discussed in general terms. The low and moderate acceptors underwent weak to strong conceptual change regarding their understanding and acceptance of evolution. The very high acceptors' acceptance of evolution and understanding of macroevolution was relatively stable over time. Their understanding and acceptance remained stable over time because they scored near the top of the scales on the initial MUM and MATE, which left little to no room for improvement on either measure.

The study findings revealed that aspects related to teachers' pre-existing conceptions, particularly for the low acceptors, were important in the teachers' abilities to undergo conceptual change related to their acceptance of evolution. For example, prior to the training, the low acceptors existing conceptions did not align with scientific understanding or acceptance of evolution. Instead, they held two incompatible explanations for evolution, one based on religion and one based on science. These teachers exhibited causal flexibility (Poling & Evans, 2002) in which they shifted their explanations and acceptance of evolution depending on the context.

Each of the low acceptors had different levels of the three relevant qualities of a learner's existing conceptions influencing the likelihood of undergoing conceptual change. These qualities include the strength of their existing ideas, the coherence of their existing knowledge, and their commitment to their existing ideas. Though scientifically inaccurate, Teresa's pre-existing knowledge about understanding and teaching evolution through a creationist perspective was strong. She held many of the common creationist misconceptions about why evolution is counter to the teachings of the Bible, and was committed to teaching through a creationist perspective. On the other hand, while Joycelyn and Julianne believed God had a role in evolutionary processes, they did not have the same strength of understanding of teaching through a creationist perspective, or of macroevolutionary concepts. Instead, they introduced creationist conceptions only in response to students' questions, and were not committed to teaching either creationist or evolutionary concepts in depth as Teresa would.

While all three of the low acceptors underwent conceptual change regarding their acceptance of evolution, they experienced different levels of change, depending upon their existing conceptions. Joycelyn and Julianne, who were not strongly committed to the teaching of science through a creationist perspective, underwent strong conceptual change about their acceptance of evolution. Joycelyn's dueling conceptions that evolution and religion were in conflict were reconciled, and she became comfortable accepting evolution, while believing in God. On the other hand, Teresa, who was much more committed to her creationist perspective, underwent weak conceptual change regarding her acceptance of evolution.

Through the CRKM, a learner's existing conceptions and motivation to learn new information interact with the qualities of the message itself. The interplay between Teresa's strength of commitment to her pre-existing creationist concepts, and her perception that the information presented during the series related to macroevolutionary concepts was wrong impeded her ability to undergo strong conceptual change regarding acceptance of evolution. While Teresa understood the content being presented, she did not find the macroevolutionary concepts, particularly about human evolution, to be plausible or compelling because they were in conflict with the teachings of the *Bible*. Furthermore, even though several scientists presented multiple lines of evidence supporting evolution, she did not find the arguments to be convincing or persuasive.

Thus, this study's findings suggest that with low acceptors of evolution, the combined effects of their pre-existing evolution conceptions and their perception that the information they were learning in the series was coherent and plausible within their existing conceptions are important in teachers' ability to undergo conceptual change. These combined effects impede low acceptors ability to undergo conceptual change about their acceptance of evolution. This finding is of importance because those aspects are inherent to an individual teacher, and are outside the direct control of the professional development program. Thus, even after attending a professional development program aligned with the CRKM, teachers' own conceptions may inhibit them from strong conceptual change.

Limitations

This study had a few limitations. First, participants were recruited to take part in the study using self-selective sampling techniques; they had to apply to participate in the program. While self-selected sampling may produce a biased sample, this bias is not of concern because this investigation is not attempting to make generalizations about an entire population. Instead, it is an exploratory study examining the effects of the training program on a group of 4th through 8th grade teachers who are highly motivated to learn about life through time, as demonstrated in the time commitment they were willing to dedicate to the project's activities. Second, the training program was limited to a maximum of 20 participants because of financial constraints and space limitations at some of the field trip localities. A total of 18 teachers completed all training and research requirements. While a sample size of 18 is adequate for conducting a quantitative study of this nature, as is a sample size of eight for a qualitative study of this nature, because of the relatively small sample size of the study, more data points are needed to fully support the results of the multiple regression analysis.

While the study explored the effects of a professional development program on participants' macroevolution PCK, it did not explore each of the five discrete components of PCK identified by Magnusson et al. (1999). The interview questions primarily focused on assessing participants' macroevolution PCK related to their knowledge about science curriculum, knowledge about students' understanding of specific science topics, and knowledge of instructional strategies for teaching science. Interview questions were not directly created to elicit the two final components of participants' PCK regarding their orientations towards science teaching or their beliefs about assessments in science. Thus, the results of this investigation provide insight into portions of participants' PCK about macroevolution, but not the entire scope of their knowledge. Further research protocols should be developed to include all five components of PCK.

Recommendations for Further Research

This study adds to the limited previous research examining the effects of an intervention on elementary and middle school teachers' acceptance and understanding of evolution, and how they teach it. Since this study targeted teachers who were interested in learning more about life through time and evolution, additional investigations should be conducted with teachers who are either neutral or resistant to learn more about evolutionary biology. Additionally, as the majority of the participants taught in urban, public schools, additional research should be conducted across a diverse population of elementary and middle school teachers to determine how a sustained professional development program impacts their knowledge and understanding of evolution and how to teach it. A primary goal of ensuring teachers are prepared to teach evolution is because teachers' knowledge and practices impact students. Thus, additional research should be conducted examining relationship among the professional development program, teachers' macroevolutionary PCK, and student understanding and acceptance of evolution.

While participants' understanding of macroevolution significantly increased as a result of attending the training, it was between the midpoint and posttest that the significant increase occurred. The session topics covered between the midpoint and posttest were: 1. the Tree of Life, which emphasized how to create and interpret phylogenies, and 2. plate tectonics and speciation, which emphasized major plate tectonic events, species concepts, and speciation. Concepts related to these last two session topics were discussed throughout the series, but they were the primary topics discussed on these two days. Additional investigations could determine whether the entire length of the *Life Through Time* training was needed, or if only presenting portions of the training program would have the same impact on increasing teachers' understanding and acceptance of evolution.

Practical Implications

The results of this study suggest that sustained professional development programs increase teachers' understanding and acceptance of evolution, and positively impact their macroevolutionary PCK. They also support prior research findings that teachers with less subject matter preparation have a lower understanding and acceptance of evolution, which negatively impacts their ability to teach it to their students. Thus, consistent with prior recommendations (Deniz, et al., 2008; Rutlegde & Mitchell, 2002) it is critical that pre-service elementary and middle school teachers be required to take a college level course on evolution which directly integrates the nature of science into the course. Additionally, since there are many challenges associated with teaching evolution and because understanding evolution is so critical to understanding biology, colleges and universities should develop a science methods course specifically designed to increase pre-service teachers' evolution and nature of science PCK. School districts, universities, and other professional development providers should offer in-service elementary and middle school teachers sustained professional development programs focused on increasing their evolutionary and nature of science PCK, being sure to help the teachers address the perceived conflict between science and religion. These sustained professional development programs should be based upon characteristics of effective professional development. Effective professional development programs are: based on standards; promote active learning, take teachers' knowledge and beliefs into consideration; emphasize both content knowledge and PCK, foster collaboration among participants; focus on inquiry-based practices; led by facilitators with appropriate expertise; provide long-term coherent plans; and are time intensive and sustained.

While educators familiar with evolution may be able to identify the concepts related to evolution in the kindergarten through 8th grade TEKS, the TEKS should be revised to explicitly identify the elementary and middle school standards related to evolution so that teachers do not have to question if or how they are required to introduce evolutionary concepts to their students.

APPENDIX A

Life Through Time Research Project Application

What will I be required to do as part of the research project?

- Attend a 9 day, integrated life and earth sciences teacher training series
- Train 5 other educators for a minimum of 6 hours in the project curriculum
- Participate in an on-line forum to reflect upon your learning
- Complete pre- and posttests, usage logs, presentation logs, and program evaluations

What is the nature of the teacher training being offered?

The Texas Natural Science Center, with support from the Institute of Museum and Library Services, is hosting a 9-day, integrated life and earth sciences teacher training series: *Life Through Time.* Educators will work with University of Texas scientists and science educators to investigate concepts in life through time utilizing techniques from investigating geological processes to interpreting the fossil record. All lunch and parking expenses are covered. Educators will receive a stipend for participating in the professional development series, as well as multiple curriculum guides and experiences which can be directly integrated into the classroom.

Who is eligible to apply?

Educators must:

- Teach 4^{th} – 8^{th} grades
- Teach a majority of students who are underrepresented in the sciences including Hispanics, African-Americans and females.
- Have a way to incorporate TEKS-aligned project materials in the classroom.

Priority acceptance will be given to teachers from Central Texas Regional Collaborative for Excellence in Science Teaching and Manor Independent School District. However, other 4^{th} through 8^{th} grade educators may also apply.

What are important dates?

Applications are due December 13, 2010. Deliberation and notification will take place by mid December.

Application Instructions

Completed applications must be received by <u>December 13, 2010</u>. The completed application may be mailed or faxed (512.471.4794) to:

Texas Memorial Museum
2400 Trinity Street
Austin, Texas 78705
Attn: *Life Through Time* Coordinator

Questions?

If you have any questions, please contact Christina Cid, Director of Education, at 512.232.5509 or via e-mail to: ccid@austin.utexas.edu

The Institute of Museum and Library Services is the primary source of federal support for the nation's 123,000 libraries and 17,500 museums. The Institute's mission is to create strong libraries and museums that connect people to information and ideas.

Applications must be received by December 13, 2010. Return to:
Texas Memorial Museum
2400 Trinity Street
Austin, Texas 78705
Attn: *Life Through Time* Coordinator

Part I: Personal Information

Name ____
(Last) (First) (Middle)
Home Address ____
City ______________________________ State ___________________ Zip ________
Home Phone _________________________ Cell Phone ______________________
E-mail ____
Will you need housing to be provided during the summer institute? ___ Yes ___No
What percentage of your time is spent working directly with students (not including planning time)?
_____ N/A _____ Less than 50% _____ 50-90% _____ 100%

Ethnicity (check one)

African-American: _____
Asian-American: _____
Caucasian: _____
Hispanic: _____
Native American: _____
Other (please describe): _____

Gender: ____________________
Current Teaching Position(s): ____
Subjects Taught: ____
Teaching Experience (Years): ____________________
Teacher Certification(s): ________________________

College/University Degree(s)

Degree	College/University	Year	Major	Minor

Number of undergraduate/graduate hours in:
Biology: _________
Chemistry: _________
Physics: _________
Earth Sciences: _________
Space Sciences: _________

Are you a member of the Central Texas Regional Collaborative for Excellence in Science Teaching or a teacher from Manor Independent School District?
_____ Yes, Central Texas Regional Collaborative _____ Yes, Manor ISD
_____No

Employer ___________________________ School Name________________________
(name of school district)

Principal/Administrator ____

School Address ____

City ______________________________ State ___________________ Zip ________

The campus where I teach qualifies as a Title I school ○ yes ○ no

The campus where I teach is a _______________ school.

(Private) (Charter) (Public) (Alternative)

Campus Data and Demographics

Percentage of students who are:

Receive free/reduced lunch ________African American ________
Asian American ________
Caucasian ________
Hispanic ________
Native American ________
Other ________

Classroom Data and Demographics

Number of students on current classroom roll who are (DO NOT use percentages):

Receive free/reduced lunch ________
African American ________
Asian American ________
Caucasian ________
Hispanic ________
Native American ________
Other ________
Total number of students _______

Male _____Female _____

Part II: Written Response Questions

Please address each of the following questions thoroughly and concisely. Please fit your answers into the space provided.

1. Briefly describe why you wish to attend this teacher training series. Please address the relevance of this activity to your current responsibilities and/or future professional plans.

2. Briefly describe how you will use your professional development experience to improve your teaching of life through time using an integrated life and earth sciences approach for all students.

3. If accepted into the program, you will be required to train other educators to use the course materials. Where do you foresee training other teachers (e.g. at your campus, at the district, state level teacher conference, etc.)? Who do you anticipate might attend the training?

Part III: Certification

I certify that all information provided on this application is complete and correct to the best of my knowledge.

Signature of Applicant   Date

No person shall be excluded from participation, denied the benefits of, or be subject to discrimination under any program or activity sponsored or conducted by The University of Texas System or any of its component institutions, on any basis prohibited by applicable laws, including, but not limited to race, color, national origin, religion, sex, or handicap.

Questions may be emailed to: Christina Cid, ccid@austin.utexas.edu

Life Through Time Commitment Letter

I understand that I am committing to the requirements and responsibilities set forth below:

- Attend 9 training sessions over a 1 year period (project year 1: February – December 2011; project year 2: February – December 2012). Two training sessions held on Saturdays in the spring, a five day training session held during the summer, and two training sessions held on Saturdays in the fall.
- Present the training to a minimum of 5 other teachers by delivering at least 6 hours of professional development. Keep presentation logs documenting the training provided.
- Participate in the online forum to share lesson ideas and resources, further connect what you learned during training to your own teaching, ask questions about content or pedagogical issues, and reflect upon your learning.
- Take pre and post content knowledge tests to demonstrate proficiency and gains in knowledge and skills.
- Complete usage logs tracking the usage of project resources.

I further understand that I will be required to participate in the programmatic assessment of the project. More information about the research project will be provided to me upon acceptance into the program.

The benefits that I will receive from my full participation in the *Life Through Time* project include:

- Increased knowledge of life through time and the ability to teach the associated concepts;
- Materials and experiences that can be directly integrated into my teaching;
- 96 SBEC continuing education credit hours;
- Access to TNSC resources;
- Opportunities to collaborate with cohort colleagues, and TNSC scientists and science educators by participating in a web-based forum; and
- An opportunity to become a statewide leader in the *Life Through Time* project by training other educators.

Printed Name: ____

Signature: _________________________________ Date: ______________________

School Principal/Administrator

I understand that _____________________________________ (name of participant) is applying to participate in the *Life Through Time* project, a rigorous, high-quality Institute of Museum and Library Services and Texas Natural Science Center-sponsored integrated life and earth sciences professional development program for teachers of grades 4-8 who teach a majority of students who are historically under-represented in the sciences.

I support the selection of this teacher as a participant *Life Through Time* teacher training series. I understand the time commitment of this project and will allow this teacher to train other teachers at my campus in the TEKS-based project curriculum.

Printed Name of Principal/Administrator: ____

Signature: ____Date: _____________________

APPENDIX B

Measure of the Understanding of Macroevolution: Pretest
– Modified from Nadelson and Southerland (2010)

Directions: *Read each of the passages. Select the best option for each of the associated items that follow.*

Questions 1- 6: Consider the figure and passage below and answer the questions that follow.

Consider the proposed evolutionary tree below. Mammals originated on land, yet whales are adapted to life in the sea and can never come onto the land. The exact process of how land animals evolved into whales has been difficult to understand. However, new discoveries in India, Afghanistan and Pakistan are providing evidence for the transition of the whale family from ancient shore-dwelling ancestors.

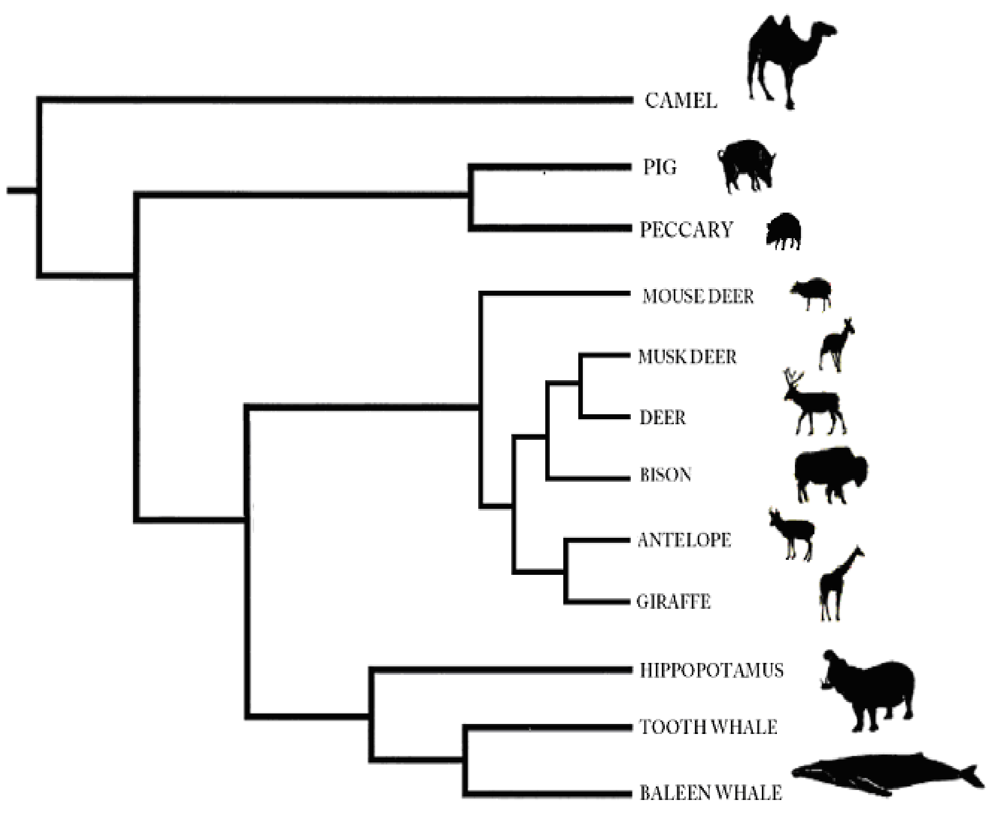


Figure 1. The evolutionary tree of some mammals.

1. The whales are classified with a group of mammals which are called even-toed ungulates. Whales have been classified as part of this group along with their closest relative the hippopotamus because:

   a. Whales and hippos are big, heavy, and have round bodies with large mouths.
   b. Whales and hippos share a more recent common ancestor.
   c. Whales and hippos have similar diets and need to live in water.
   d. Whales and hippos display similar social and parenting behaviors.

2. The chart above suggests that:

   a. The animals in this classification tree have four legs.
   b. Baleen Whales are not related to camels.
   c. Whales are more closely related to giraffes than to bison.
   d. Whales are more closely related to deer than to pigs.

3. According to evolutionary theory, whales have evolved from land animal ancestors over time. How much time do you think the evolution process might have taken?

   a. Fifty million years.
   b. Five million years.
   c. Five hundred thousand years.
   d. Five hundred million years.

4. The fossils that are being examined to determine the ancestor in the evolutionary pathway of whales have been found in areas of Pakistan, Afghanistan, and India, places that are now well above sea level. The most scientifically reasonable explanation for the location of the fossils being examined is:

   a. Predators of whale ancestors carried their prey to this area to eat them.
   b. When the whales died their skeletons floated to the top of the ocean where they drifted ashore and became fossils.
   c. This area was most likely once covered with water and the shore dwelling ancestors of whales once lived in these areas, died, and their skeletons were fossilized.
   d. The great meteor impact caused tidal wave that forced these animals into these areas trapping them causing them to die, and their skeletons were fossilized.

5. The evolutionary history and development of whales has been hotly debated. Recently there has been a major shift in our understanding of the processes used to detail whale evolution. This indicates that:

   a. Gaps in the fossil records will never allow us to fully understand evolution.
   b. Scientists studying evolution typically present ideas with very little evidence, leaving it to others to find proof of their ideas.
   c. Aspects of evolution are constantly being challenged and explored in light of new evidence.
   d. Much of the science of evolution is based on speculation that can easily be changed when scientists think of new ideas.

6. The origins of the transformation from land animal to sea creature may be observed among some wild sheep who have lived on the coast for hundreds of years. These sheep like to eat seaweed and kelp so much that they are often observed swimming into the water to eat it. If we returned millions of years later to observe these animals what might you see?

   a. Sheep who wanted to be better swimmers and so developed the ability to swim great distanced to eat kelp.
   b. Two distinct but related sheep like organisms, one that lives in the water and eats kelp, the other lives on land and eats plants.
   c. These sheep will become extinct because they will not be able to find other food and only their fossil will remain.
   d. There are so many possible outcomes that there is really no way to predict what will be seen.

Questions 7-12: Consider the two figures and passage below and answer the questions that follow.

The evolution of the eye has been studied extensively. It is a good example of an organ that at present has a wide range of forms in a wide variety of species (see Figure 2). Most experts think that all modern eyes have their origins dating back some 540 million years. An examination of the density of photoreceptors of the pigment cup and the complex eye reveal a variation within species as well as between species. The plots of the relative density of photoreceptors of the present day Nautilus and Octopus are presented in Figure 3.

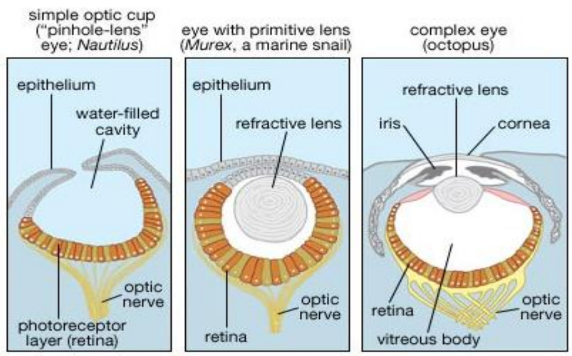


Figure 2: The different levels of eye complexity in mollusks.

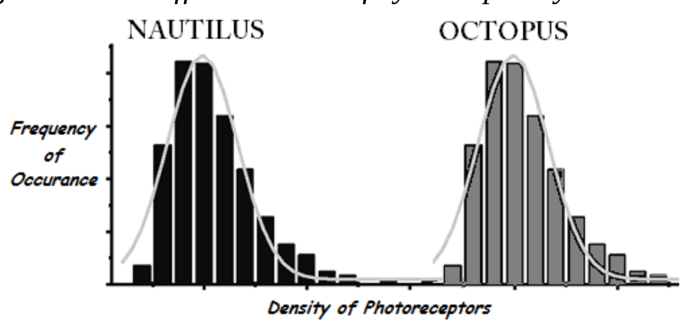


Figure 3: Variation in the relative density of photoreceptors in nautilus and octopus eyes

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7. In the evolution of the molluscan eye, it is apparent that some fundamental characteristics are retained. This supports the idea that:

    a. The organisms displaying these fundamental characteristics all have descended from an ancestor who most likely also had eyes.
    b. These are the only features that are effective for sight and therefore animals want to keep them so that they can see.
    c. Eyes are essential for survival of species so organisms and struggle and work to retain these features.
    d. Mollusk eyes have such similar features to all other seeing marine organisms that none of these eyes could have developed independently.

8. Some speculate that the eye is too complex to have resulted from evolution. Yet, evidence suggests organisms may have had eyes for nearly 500 million years. What might scientists infer about the eyes of ancient organisms?

    a. Only animals living in the bright sunlight develop eyes because they need them and use them.
    b. Eyes would bear no resemblance to how eyes are structured today, and would not be recognized as eyes.
    c. The eyes of ancient organisms would have some characteristics that are similar to eye found in organisms alive today.
    d. Only animals with bones would really be trying to develop useful eyes.

9. Most vertebrate fossils are the bones of these ancient organisms, and it is unlikely that we will find fossils of their eyes. This is because:

    a. Animals close their eyes when they die and the eyes are buried under layers of fossils.
    b. Primitive eyes were so small that they are easily overlooked as fossils.
    c. Primitive eyes were so different that scientists are not looking for the right structures.
    d. Eye tissue typically decays before it can form fossils.

10. There is a variation in the number and density of photoreceptors in the eyes (see figure 3) within a population. This is an important consideration when trying to understand evolution because:

    a. Some individuals in a population are trying harder to see better than others.
    b. The variation in eye structure within a population can lead to the development of new eye structures.
    c. There are variations happening within all populations and they have no evolutionary significance.
    d. Variations indicate a species is no longer evolving but now stabilized.

11. Evidence for the evolution of the eye is based primarily on the observations of organisms alive today. This means:

    a. Since present day animals have all developed very complex eyes, useful inferences about changes in primitive eyes are very difficult to make.
    b. Scientists must assume that the eyes of organisms today are the same as their extinct ancestors.
    c. Eyes are a recent development, evolutionarily speaking, and scientist cannot understand the structure of the eyes in the past based on evidence of eyes today.
    d. The structure of the eyes in some organisms today support scientists' views of how eyes developed over time.

12. Different organisms are classified based on similar functions and forms. All of the eyes above in figure 2 are from a group of animals referred to as mollusks. Yet, the eyes of these three species of organisms do not seem to be very similar in structure, which suggests that classification of these organisms has been based on evidence that indicates:

    a. They can be traced back to a common ancestor that had a primitive eye.
    b. That they all live in a similar location and need eyes that allow them to see in the water.
    c. They want to be able to see in the water to catch prey and avoid predators.
    d. Mollusks' eyes are not considered when grouping these organisms together.

Questions 13-18: Consider the figure and passage below and answer the questions that follow.
Extinction is extremely important in the history of life. It can be a frequent or rare event within a lineage. Every lineage has some chance of becoming extinct. Over 99% of the species that have ever lived on Earth have gone extinct. This diagram illustrates the evolution lineages of several animal species.

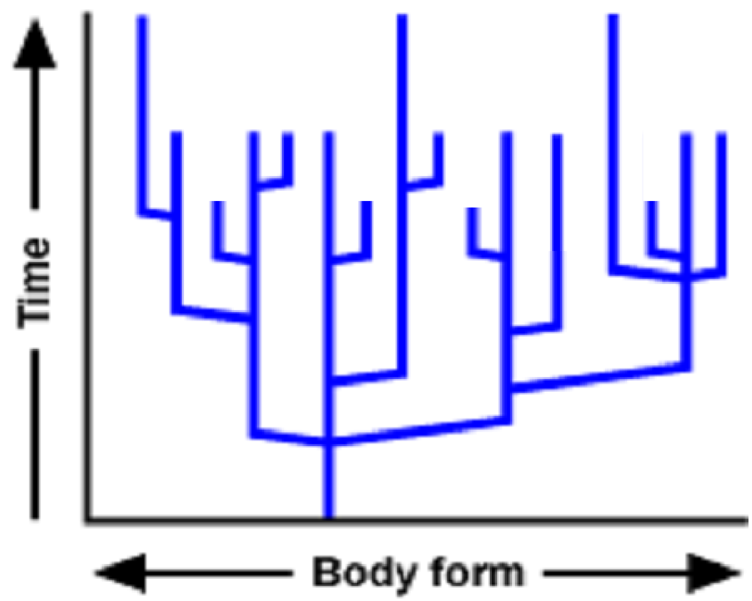


Figure 4: The historical development of the lineages of several animal species.

13. The diagram above indicates that all of the organisms originated from the same:

    a. Kingdom.
    b. Relatives.
    c. Location on the planet.
    d. Ancestor.

14. If each of the vertical lines in the diagram above represents a lineage, what is being shown about the number of living species present over time?

    a. Increases and decreases in the number of species present over time.
    b. Constantly diversified into an increased number of species with different body forms.
    c. Mostly remained unchanged and stable and have experience little change over time.
    d. Constant, yet gradual, decrease in number of species and body forms.

15. The branching of the animal species as displayed above would happen:

    a. Everyday.
    b. Over relatively long periods of time – millions of years.
    c. Occur within a few generations.
    d. Within the life span of an organism.

16. The formation of branching diagrams like the one presented above is based on:

    a. Common names of the organisms.
    b. Genes and body structures.
    c. Habitat in which modern organisms are now naturally found.
    d. Elevation and location in which the ancient fossils were discovered.

17. A number of lineages in the diagram terminate prior to the top of the tree. This indicates that these species are now extinct. Our awareness of their existence is based on fossils and this suggests that they:

    a. Were organisms with bones, exoskeletons, or left impressions.
    b. All had similar life cycles because they are all present in the fossil record.
    c. Were thought to be primarily prey killed off by the surviving predators.
    d. Died in locations in which there was no more food.

18. The branching in the diagram above indicates the development of several new species. When new species arise:

    a. New species immediately appear different and that is why the branch is created.
    b. The original species will no long have the need or desire to evolve.
    c. The original species will soon become extinct because the new species is better adapted to the environment.
    d. New species have characteristics that are similar to the original species.

Questions 19-23: Consider the figure and passage below and answer the questions that follow.

The graphic below is a suggested evolutionary pathway of the African Great Apes. The arrangement of this pathway is based on genetic information taken from the mitochondria of the various apes.

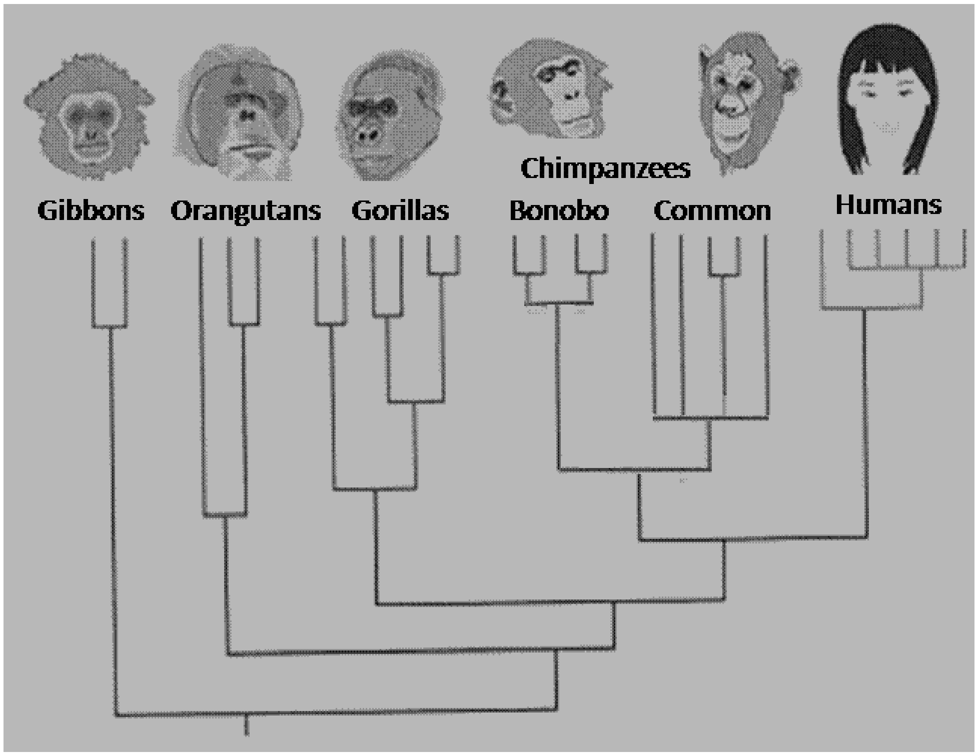


Figure 5. A hypothesized evolutionary lineages of the African Great Apes.

19. The diagram above suggests that:

a. Gibbons and Orangutans are more closely related than Gibbons and Humans.
b. Humans are much more complex than the other apes.
c. Humans and Chimpanzees are the most closely related of all the Great Apes.
d. Gibbons are unrelated to Humans.

20. The diagram above suggests that:

a. Orangutans include the most recently evolved species and Gibbons are the most ancient species of apes.
b. There has always been at least 5 species of Great Apes.
c. Gorillas represent the most diverse of the different groups of Great Apes.
d. Humans and Chimpanzees share a more recent common ancestor than Gibbons and Orangutans.

21. The African Great Apes are theorized to have evolved from a common ancestor. Given that this process took place over time, how much time do you think the process of evolution in this group of organisms might take?

a. Thirty million years.
b. Three billion years.
c. Thirty thousand years.
d. Three million years.

22. The fossil record for early humans is very sparse compared to many other organisms. In the context of the Great Ape tree this means:

a. Much of the evolutionary relationships of humans and the other Great Apes is opinion and based on guess.
b. Analysis of genetic codes and anatomy are used to derive such relationships.
c. The evolutionary relationships of humans are relative easy to determine based on the wide variety of humans alive today.
d. Humans have not undergone many evolutionary changes and remain at the top of the tree.

23. In advanced discussions of the evolution of the Great Apes, one will see a number of different evolutionary pathways, each suggesting a different relationship between the different groups of Apes. These discrepancies suggest:

a. Scientists remain uncertain if any of the Great Apes are really related and are continuing to try to prove this.
b. Scientists remain uncertain why humans would want to evolve and are continued to be seen as the superior species.
c. Anything aside from fossils is a weak form of evidence for the support of evolutionary theory.
d. Processes and small differences in methods can produce very different evidence that can be interpreted in different ways.

Question 24-27: ***Consider the figure and passage below and answer the questions that follow.***

The graphic below is a map depicting where the fossils of various organisms have been found on different continents. This map also depicts our best understanding of the relative position of some of the continents in the earth's early history.

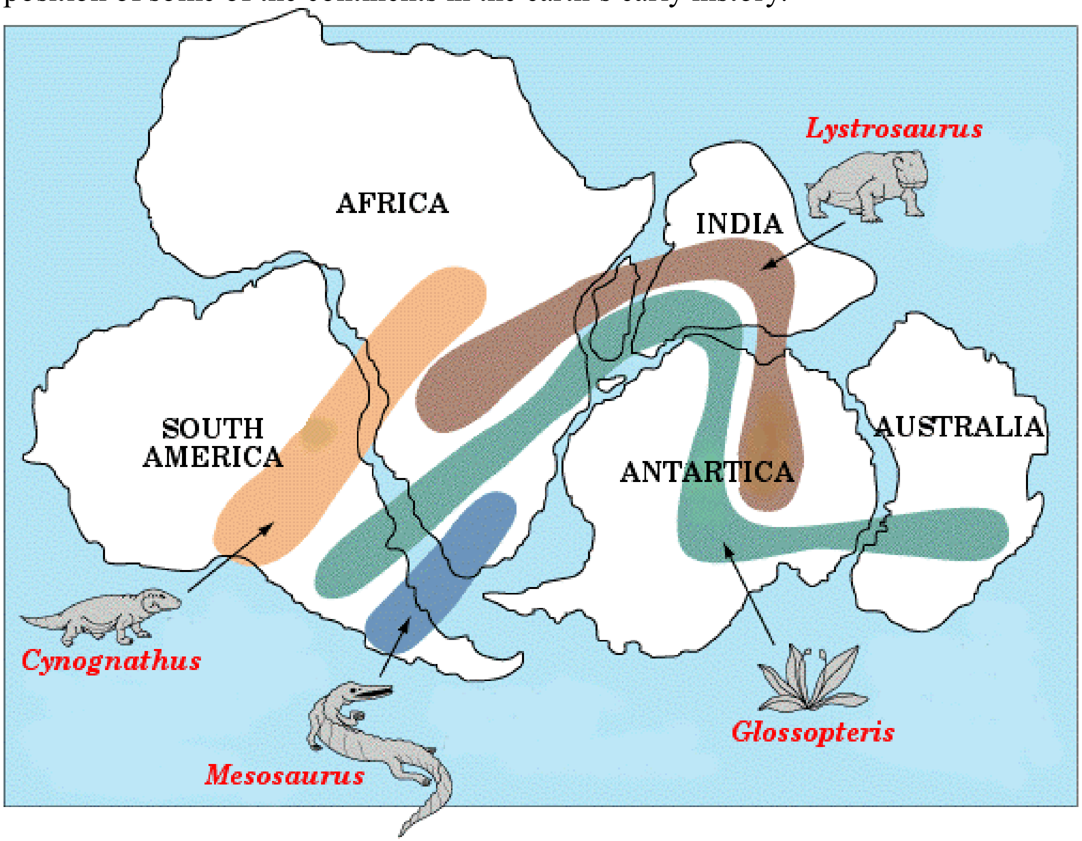


Figure 6: The distribution of fossils for 4 species across today's continents. The map shows how the continents may have once been located.

24. The separation of the continents and the separation of the organisms on these continents allowed for:

    a. Extinction, as the organisms were separated they could not survive as smaller groups.
    b. The production of new species, as groups of organisms were permanently separated.
    c. Organisms to remain unchanged, given the very slow movement of the continents and the slow rate of evolution.
    d. Organisms to interbreed, as their home ranges changed they joined together with other groups of organisms.

25. If a similar fossil was found on different continents, scientists might infer that:

    a. The continents involved were once connected.
    b. Eventually, the organisms will want to spread out and will be found on every continent.
    c. They must have come from different species but all look the same.
    d. The organisms were aware enough to know it was vital to move between continents.

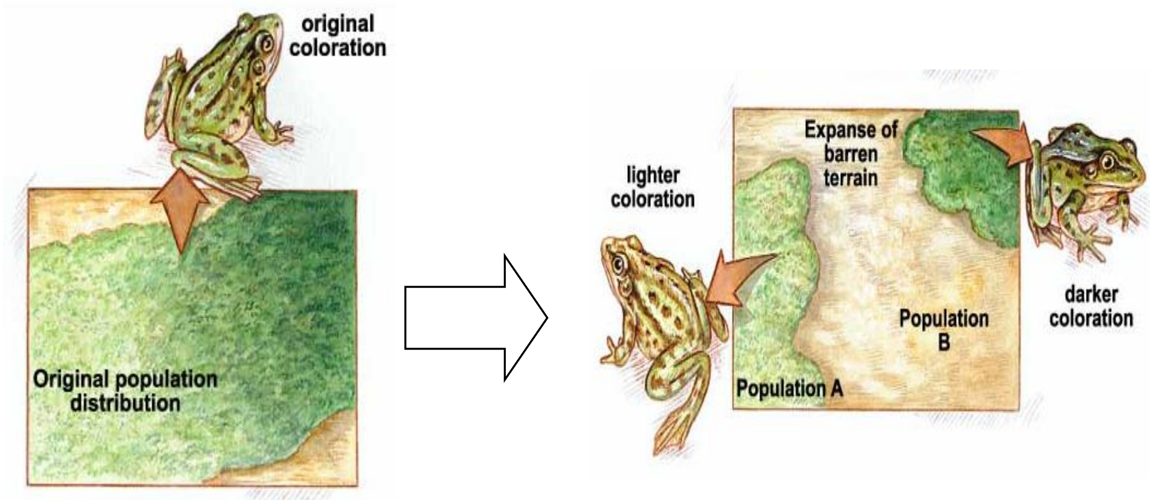
26. The theory of plate tectonics was largely discredited when it was first proposed. Fossil evidence (as shown on the graphic seen in Figure 6) gave additional support to this theory. The theory then began to be much more widely accepted by scientists. This demonstrates that:

    a. Theories are often supported by a number of different lines of evidence.
    b. Scientific theories change very easily and are frequently just seen as hunches.
    c. Knowledge about historical events is particularly weak.
    d. Nobody can ever really know how plate movement as described by plate tectonics takes place.

27. The supercontinent depicted in the graphic is known as Gondwana. This supercontinent existed roughly:

    a. Five million years.
    b. One and a half billion years.
    c. One hundred fifty million years.
    d. Three hundred and fifty thousand years.

28. Explain in as much detail as possible how the single species of frog found in the graphic on the **left** could give rise to the two species of frog found in the graphic on the **right**.



Measure of the Understanding of Macroevolution: Midpoint test
– Modified from Nadelson and Southerland (2010)

Questions 1- 6: Consider the figure and passage below and answer the questions that follow.

Consider the proposed evolutionary tree below. Dinosaurs originated as walking animals with scaled skin; however, birds have feathers and are capable of flight. When *Archaeopteryx* was found, it provided clues as to how birds evolved from reptile ancestors. However, not until the discoveries of fossils of feathered ground-running dinosaurs in China were paleontologists able to explain the transition from featherless theropod dinosaurs to living birds.

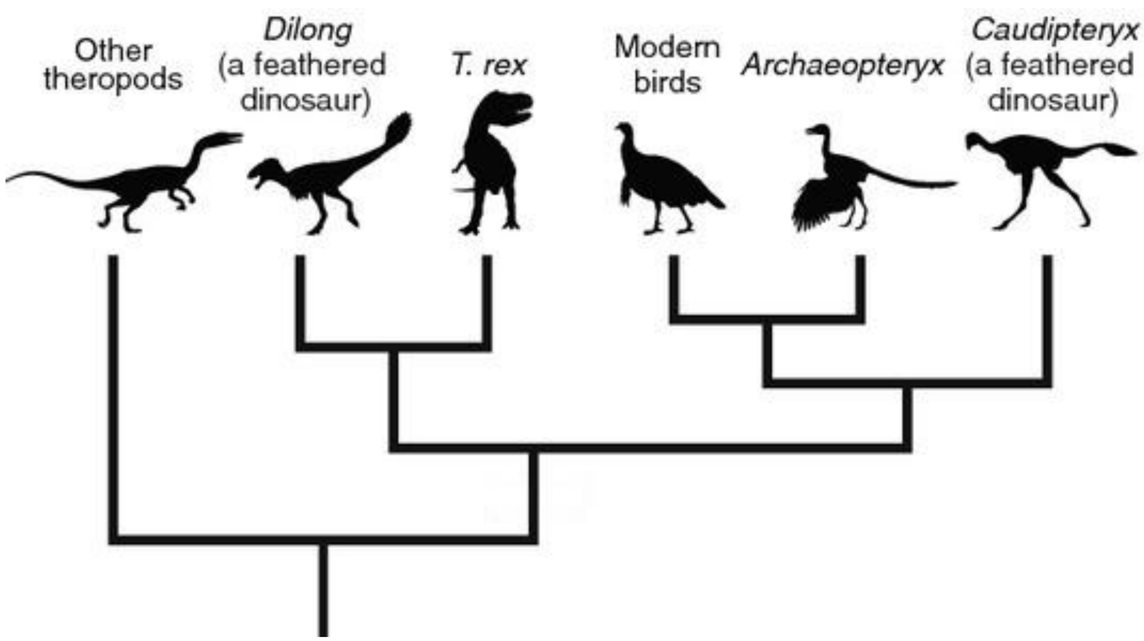


Figure 1. The evolutionary tree of theropod dinosaurs. (adapted from Thanukos, 2009)

1. Birds are classified within a group of bipedal, meat-eating dinosaurs called theropods. Birds have been classified as part of this group along with their closest relative, *Archaeopteryx*, because:

   a. Birds and *Archaeopteryx* have feathered wings.
   b. Birds and *Archaeopteryx* had similar diets and needed to live in trees.
   c. Birds and *Archaeopteryx* displayed similar social and parenting behaviors.
   d. Birds and *Archaeopteryx* share a recent common ancestor with *Dilong*, *T. rex*, and *Caudipteryx*.

2. The chart above suggests that:

a. Birds are more closely related to *T. rex* than to *Caudipteryx*.
b. Birds are more closely related to *Caudipteryx* than to *Dilong*.
c. All the animals in this evolutionary tree have teeth.
d. Birds are not dinosaurs.

3. According to evolutionary theory, birds have evolved from theropod dinosaur ancestors over time. How much time do you think the evolution process might have taken?

a. One hundred thousand years
b. One million years
c. One hundred million years
d. Ten million years

4. Many of the fossils that are being examined to identify ancestors in the evolutionary pathway of birds have been found in layered lake and volcanic ash deposits in northeastern China, places that are now agricultural fields. The most scientifically reasonable explanation for the location of the fossils is:

a. This area was once covered with lakes and volcanoes.-When the volcanoes erupted, ash fell into the lakes, contributing to the sediments that buried the animals that fell into the lakes.
b. Predators of feathered dinosaurs carried their prey into lakes to eat them.
c. When the feathered dinosaurs died, their remains were buried by farmers tilling their fields.
d. Lava flowing from volcanoes in the area carried the bodies of feathered dinosaurs and deposited them into lakes, where their skeletons were fossilized.

5. The evolutionary history of birds has been hotly debated. Recently, there has been a major shift in our understanding of the processes that have driven bird evolution. This indicates that:

a. Gaps in the fossil records will never allow us to fully understand evolution.
b. Aspects of evolution are constantly being challenged and explored in light of new evidence.
c. Scientists studying evolution typically present ideas with very little evidence, leaving it to others to find proof of their ideas.
d. Much of the science of evolution is based on speculation that can easily be changed when scientists think of new ideas.

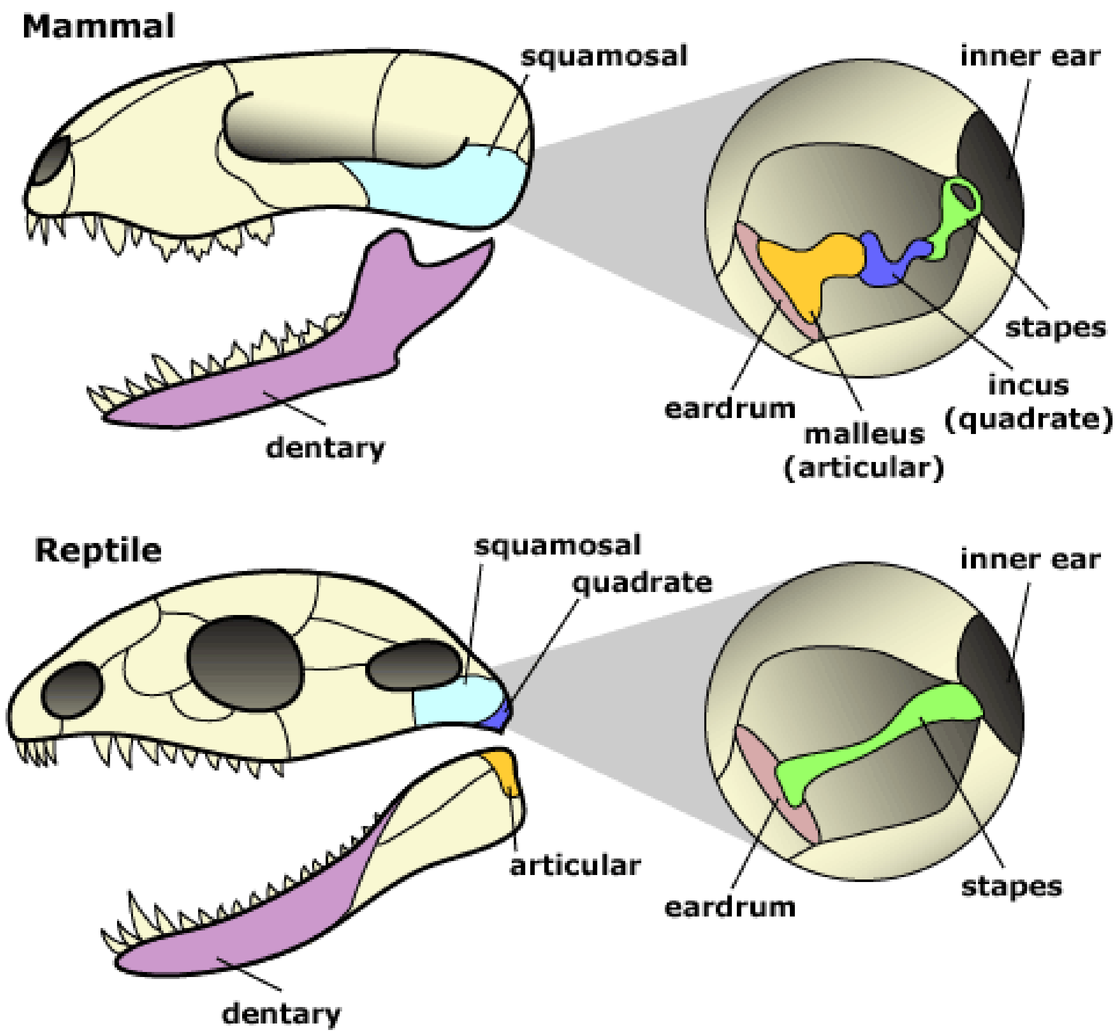
6. The origins of the transformation from a land walking animal to a flying animal may be observed among some lizards that have lived in a forest of trees for hundreds of years. These lizards like to eat flying insects so much that they are often observed leaping from tree branch to tree branch to capture and eat them. If we returned millions of years later to observe these animals what might we see?

    1. Lizards that wanted to capture more flying insects developed the ability to fly from tree to tree over great distances.
    2. Two distinct but related lizard-like organisms, one that lives in the trees and eats flying insects, the other lives on land and eats crawling insects.
    3. These lizards will become extinct because they will not be able to find other food and only their fossils will remain.
    4. There are so many possible outcomes that there is really no way to predict what will be seen.

Questions 7-12: Consider Figure 1 and the passage below to answer the questions that follow.

Mammals have one bone in the jaw and three bones in the ear. Reptiles have many bones in the jaw and one bone in the ear. During the evolutionary remodeling of the mammalian skull, the quadrate and articular bones became incorporated into the middle ear as two of the three bones that transmit sound from the eardrum to the inner ear. Compare the colors of the bones in the diagrams below to discover which bones mammals and reptiles inherited from their common vertebrate ancestor and how mammals developed their own style of ear from these bones.

Figure 1: The evolution of the mammalian jaw and ear bones. (from Understanding Evolution, 2011b).



7. In the evolution of the mammalian jaw and ear bones, it is apparent that some fundamental characteristics are retained. This supports the idea that:
   a. The organisms displaying these fundamental characteristics all have descended from an ancestor who most likely also had ears.
   b. Simple ears without several ear bones are not adequate to support survival and reproduction.
   c. Mammal ears evolved in increments from much simpler versions that performed the same basic function.
   d. Reptile ears have such similar features to all other hearing vertebrates that none of these ears could have developed independently.

8. Some speculate that the mammalian ear is too complex to have resulted from evolution. Yet, evidence suggests some vertebrates may have had a stapes for over 300 million years. What might scientists infer about the ears of ancient vertebrates?

   a. Only animals living on land developed ears because ears helped them survive.
   b. Ears would bear no resemblance to how ears are structured today, and would not be recognized as ears.
   c. The ears of ancient vertebrates would have some characteristics that are similar to ears found in vertebrates alive today.
   d. Only animals with bones would develop useful ears.

9. Most vertebrate fossils are the bones of these ancient organisms, and it is difficult to find fossils of the ear structures. This is because:

   a. Cartilage serves as the supporting structure for the detached ear bones and after the animal dies it is buried under layers of fossils.
   b. Primitive ears were so small that they are easily overlooked as fossils.
   c. Primitive ears were so different that scientists are not looking for the right structures.
   d. Ear structures such as muscles, nerves, and vascular tissue typically decay before it can form fossils.

10. There is a variation in the shape and size of the bones in the ears within a population. This is an important consideration when trying to understand evolution because:

    a. Some individuals in a population are trying harder to hear better than others.
    b. The variation in ear structure within a population can lead to the development of new ear structures.
    c. There are variations happening within all populations and they have no evolutionary significance.
    d. Variations indicate a species is no longer evolving but now stabilized.

11. Evidence for the evolution of the ear is based primarily on the observations of vertebrates that are alive today. This means:

    a. Because present day animals have all developed very complex ears, useful inferences about changes in primitive ears are very difficult to make.
    b. Scientists must assume that the ears of vertebrates today are the same as their extinct ancestors.
    c. Ears are a recent development, evolutionarily speaking, and scientists cannot understand the structure of the ears in the past based on evidence of ears today.
    d. The structure of the ears in some vertebrates today supports scientists' views of how ears developed over time.

12. Different organisms are classified based on similar functions and forms. The jaws and ear bones above in Figure 1 are from reptiles and mammals. Yet, the jaw and ear bones of these two groups of organisms are not the same in structure, which suggests that classification of these organisms as vertebrates has been based on evidence that indicates:

    a. They can be traced back to a common ancestor that had a primitive ear.
    b. That they all live in a similar location and needed ears that allow them to hear on the land.
    c. They want to be able to hear on land to catch prey and avoid predators.
    d. The jaw and ear bones are not considered when grouping these organisms.

Questions 13-18: Consider the figure and passage below and answer the questions that follow.

Extinction is extremely important in the history of life. It can be a frequent or rare event within a lineage. Every lineage has some chance of becoming extinct. Over 99% of the species that have ever lived on Earth have gone extinct. This diagram illustrates the evolutionary history of several flowering plant species.

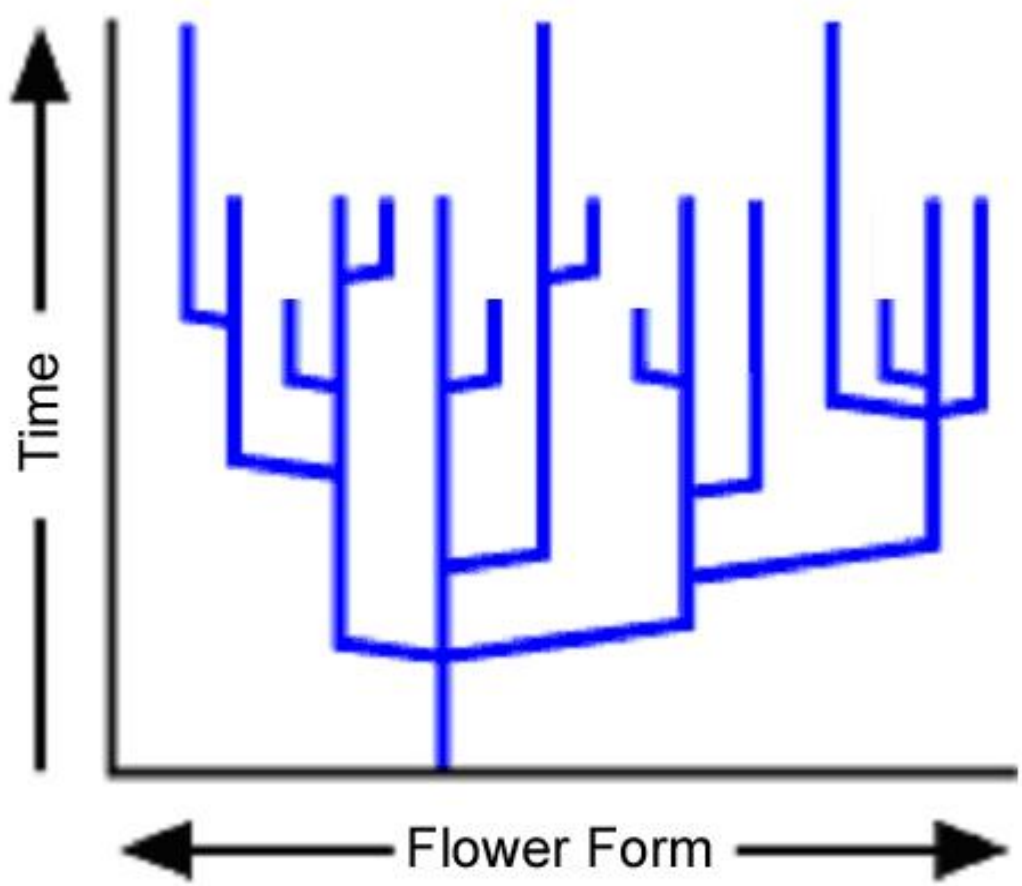


Figure 4: The historical development of the lineages of several flowering plant species. (adapted from Nadelson & Southerland, 2010)

13. The diagram above indicates that all of the plant species originated from the same:
    a. Family.
    b. Ancestor.
    c. Seed.
    d. Location on the planet.

14 If each of the vertical lines in the diagram above represents a lineage, what is being shown about the number of living species present over time?

a. Increases and decreases in the number of species present over time.
b. Mostly remained unchanged and stable and have experienced little change over time.
c. Constant, yet gradual, decrease in number of species and flower forms.
d. Constantly diversified into an increased number of species with different flower forms.

15. The branching of the plant species as displayed above would happen:

a. Every day.
b. Occur within a few generations.
c. Within the life span of an organism.
d. Over relatively long periods of time – millions of years.

16. The formation of branching diagrams like the one presented above is based on:

a. Common names of the organisms.
b. Genes and flower structures.
c. Ecosystem in which modern organisms are now naturally found.
d. Elevation and location in which the ancient fossils were discovered.

17. A number of lineages in the diagram terminate prior to the top of the tree. This indicates that these species are now extinct. Our awareness of their existence is often based on fossils and this suggests that they:

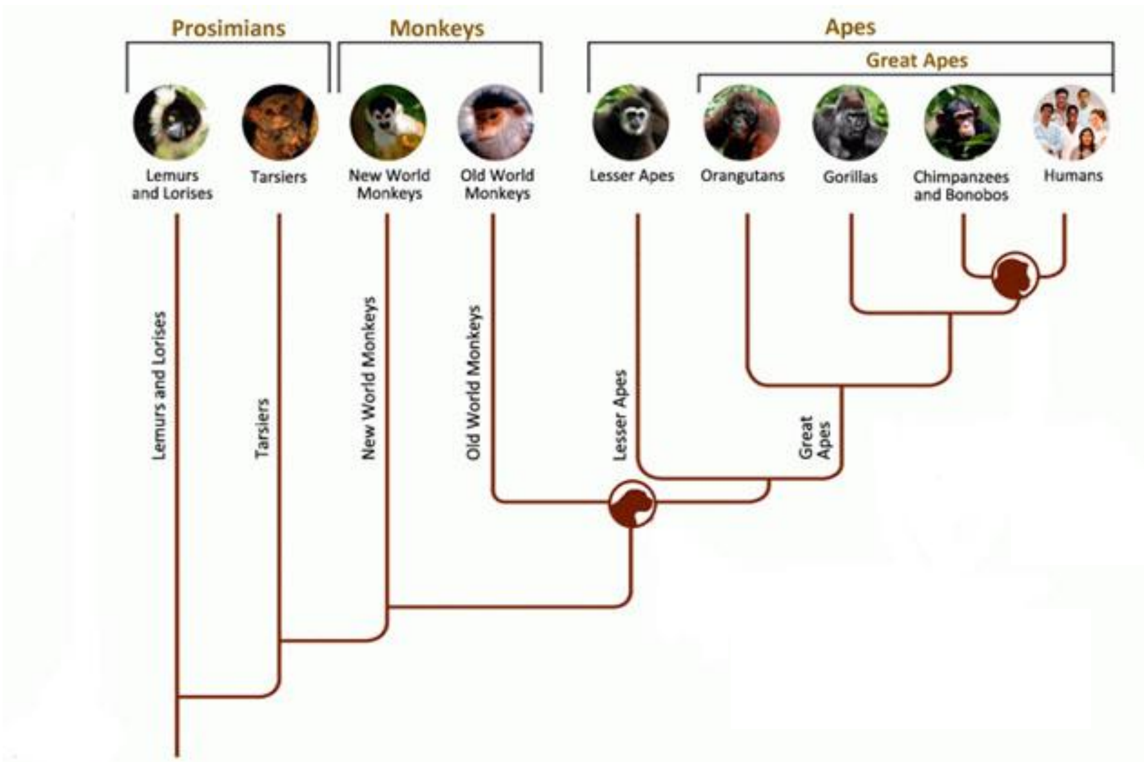
a. All had similar life cycles because they are all present in the fossil record.
b. Were preserved as compactions or impressions.
c. Were thought to be primarily plants that were uprooted.
d. Died in locations in which there was no sunlight.

18. The branching in the diagram above indicates the development of new species. When new species arise, generally:

a. New species have characteristics that are similar to the original species.
b. New species immediately appear very different and that is why the branch is created.
c. The original species will no longer have the need or desire to evolve.
d. The original species will soon become extinct because the new species is better adapted to the environment.

Questions 19-23: Consider the figure and passage below and answer the questions that follow.

The graphic below is a suggested evolutionary tree of the Primates. The arrangement of this tree is based on genetic information taken from the mitochondria of the various primates. (adapted from Smithsonian National Museum of Natural History, 2010)



19. The diagram above suggests that:

   a. Humans and Chimpanzees and Bonobos are the most closely related of all the Great Apes.
   b. Lesser Apes and Orangutans are more closely related than Lesser Apes and Humans.
   c. Humans are much more complex than the other apes.
   d. Lesser Apes are unrelated to Humans.

20. The diagram above suggests that:

a. Great Apes include the most recently evolved species and Lesser Apes are the most ancient species of apes.
b. Old World Monkeys, Lesser Apes, and Orangutans share a more recent common ancestor than do Humans and Chimpanzees and Bonobos.
c. There has always been at least 5 species of Great Apes.
d. The common ancestor of Chimpanzees, Bonobos, and Humans existed before the common ancestor of Orangutans and Gorillas.

21. All Great Apes are theorized to have evolved from a common ancestor. Given that this process took place over time, how much time do you think the process of evolution in this group of organisms might take?

a. Thirty thousand years.
b. Three billion years.
c. Thirty million years.
d. Three million years.

22. The fossil record for early humans is very sparse compared to many other organisms. In the context of the Primate tree this means:

a. Much of the evolutionary relationships of humans and the other Primates is opinion and based on guess.
b. The evolutionary relationships of humans are relatively easy to determine based on the wide variety of humans alive today.
c. Humans have not undergone many evolutionary changes and remain at the top of the tree.
d. Analysis of genetic codes and anatomy are used to derive such relationships.

23. In advanced discussions of the evolution of the Great Apes, one will see a number of different evolutionary trees, each suggesting a different relationship between the different groups of Apes. These discrepancies suggest:

a. Processes and small differences in methods can produce very different evidence that can be interpreted in different ways.
b. Scientists remain uncertain if any of the Great Apes are really related and are continuing to try to prove this.
c. Scientists remain uncertain why humans would want to evolve and are continued to be seen as the superior species.
d. Anything aside from fossils is a weak form of evidence for the support of evolutionary theory.

Question 24-27: ***Consider the figure and passage below and answer the questions that follow.*** The graphic below is a map depicting where the fossils of 2 species of trilobites and 2 species of graptolites have been found on different continents. This map also depicts our best understanding of the relative position of some of the continents in Earth's early history.

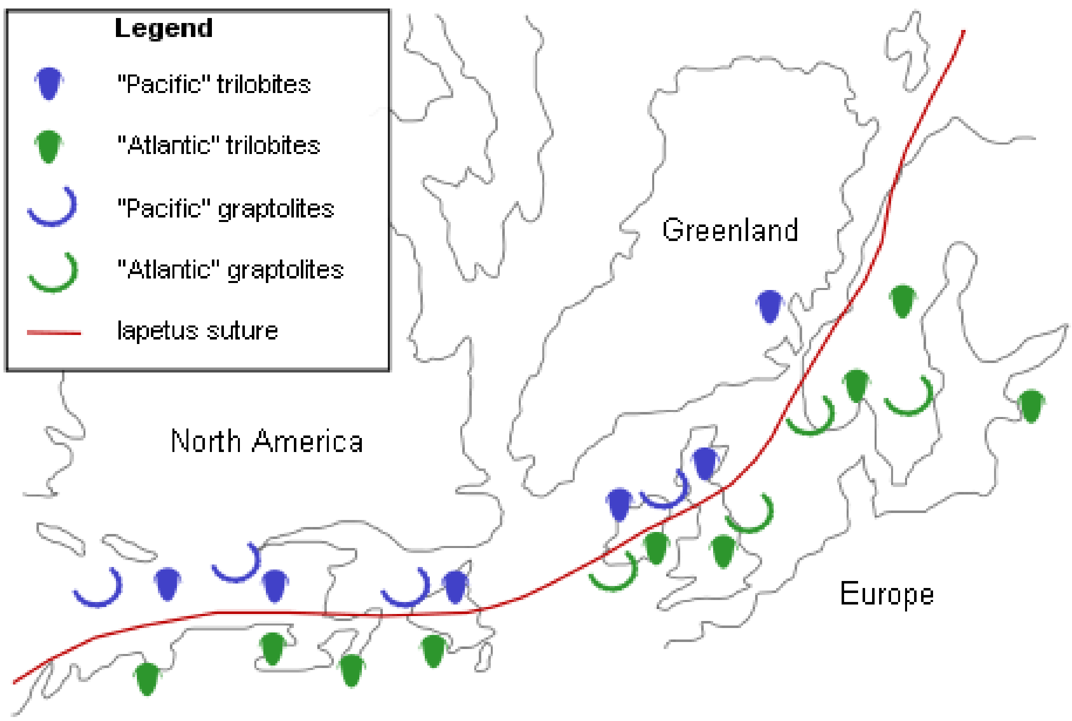


Figure 6: The distribution of fossils for 2 species of trilobites and 2 species of graptolites across today's continents. The map shows how the continents may have once been positioned. (adapted from Woodlouper, 2008)

Scientists think that although trilobites and graptolites were marine organisms, they had many different lifestyles. For example, trilobites and graptolites lived in both shallow and deep water with most living in seas but evidence suggests that some may have been able to live in freshwater. Scientists think that trilobites and graptolites could not cross deep oceans. The distribution of trilobites and graptolites suggests that an ocean, known as the Iapetus Ocean, once divided Europe and North America but this ocean closed up when all the continents joined together in the super-continent of Pangaea. When Pangaea broke up, the Atlantic Ocean formed, separating Europe and North America again.

24. The separation of the continents and the separation of the organisms on these continents allowed for:

a. Organisms to interbreed, as their home ranges changed they joined together with other groups of organisms.
b. Organisms to remain unchanged, given the very slow movement of the continents and the slow rate of evolution.
c. Extinction, as the organisms were separated they could not survive as smaller groups.
d. The production of new species, as groups of organisms were permanently separated.

25. If a similar fossil was found on different continents, scientists might infer that:

a. The organisms were aware enough to know it was vital to move between continents.
b. They must have come from different species but all look the same.
c. The continents involved were once connected.
d. Eventually, the organisms will want to spread out and will be found on every continent.

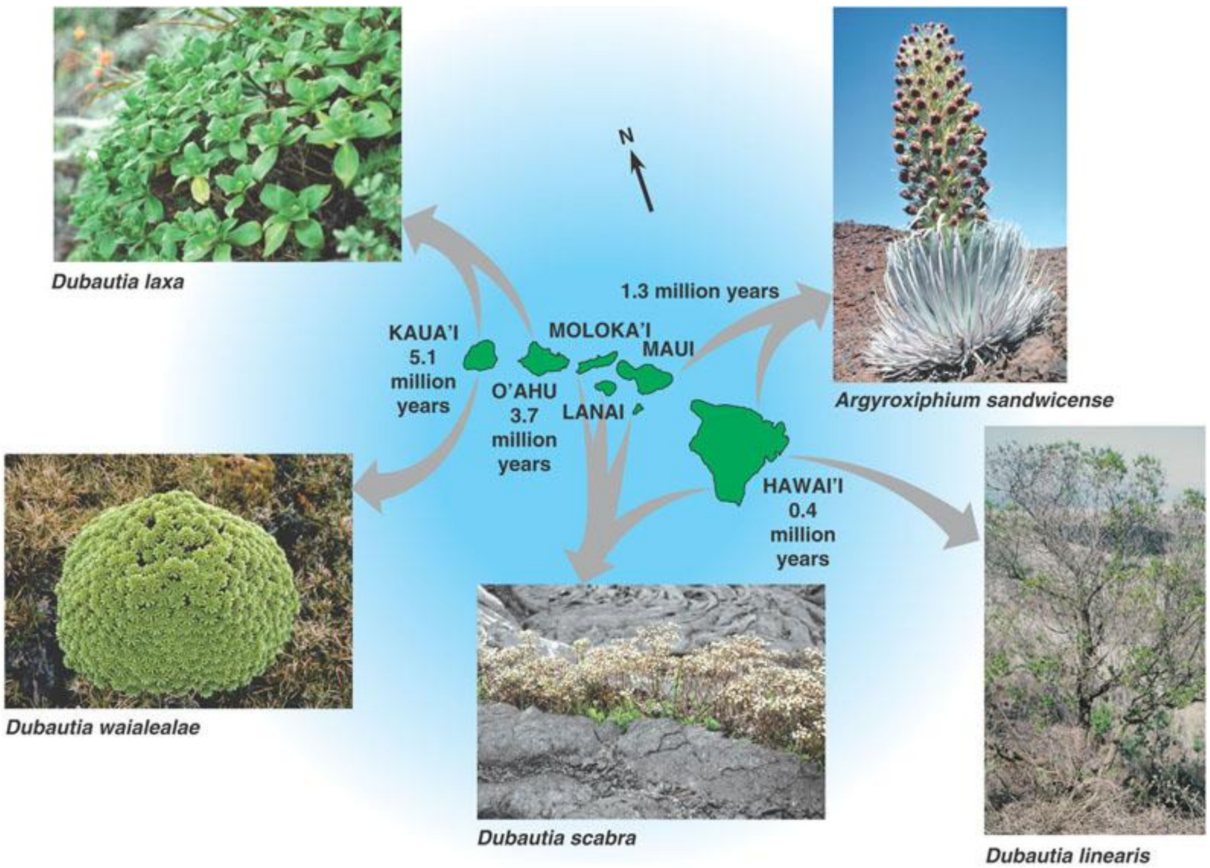
26. The theory of plate tectonics was largely discredited when it was first proposed. Fossil evidence (as shown on the graphic seen in Figure 6) gave additional support to this theory. The theory then began to be much more widely accepted by scientists. This demonstrates that:

a. Knowledge about historical events is particularly weak.
b. Theories are often supported by a number of different lines of evidence.
c. Scientific theories change very easily and are frequently just seen as hunches.
d. Nobody can ever really know how plate movement as described by plate tectonics takes place.

27. The super-continent depicted in the graphic is known as Pangaea. This super-continent existed roughly:

a. Three hundred and fifty thousand years.
b. Five million years.
c. Two hundred fifty million years.
d. One and a half billion years.

28. Explain in as much detail as possible how a single species of ancestral tarweed that arrived on the Hawaiian islands about 5 million years ago from North American could have given rise to these five species known collectively as the "silversword alliance." (adapted from "Adaptive Radiation", n.d.)



Measure of the Understanding of Macroevolution: Posttest
– Modified from Nadelson and Southerland (2010)

Questions 1- 6: Consider the figure and passage below and answer the questions that follow.
Consider the proposed evolutionary tree below. Squamate reptiles (lizards and snakes) originated from non-venomous reptiles. Snakes, including rattlesnakes, cobras and garter snakes produce venom to kill their prey. When snake venom genes were found by biologists, they provided clues as to how snakes evolved from non-venomous lizard-like ancestors. These genes were found to be similar to genes in the mouth glands of lizards that are closely related to snakes. However, not until the discoveries of snake fossils combined with additional studies of reptile DNA were scientists able to explain the ancient origin of venom in snakes.

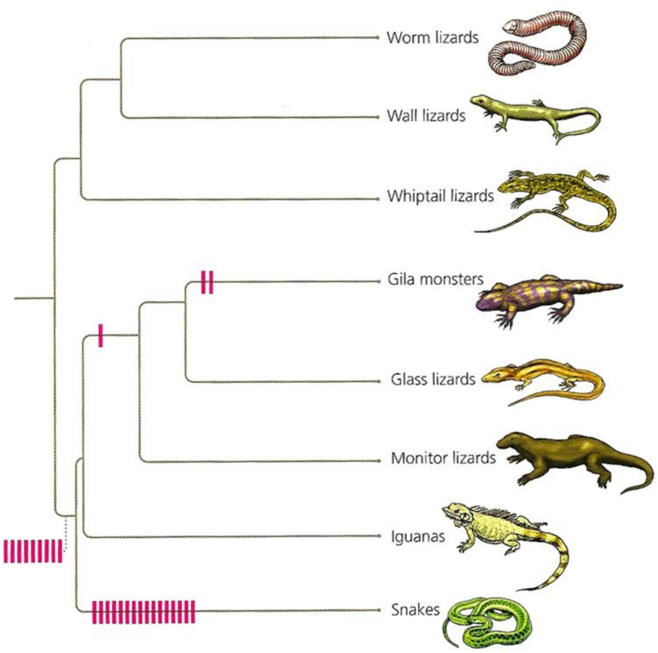


Figure 1. An evolutionary tree of squamate reptiles (lizards and snakes). The bars mark the appearance of venom genes within lineages. (Zimmer, 2010, p. 164)

1. Snakes are classified within a group of lizards called the "venom clade". Snakes have been classified as part of this group along with iguanas because:

   a. Snakes and Iguanas are both reptiles.
   b. Snakes and Iguanas have similar diets and need to live in warm environments.
   c. Snakes and Iguanas display similar predatory behaviors.
   d. Snakes and Iguanas share a recent common ancestor that possessed venom genes.

2. The tree above suggests that:

   a. Snakes are more closely related to Whiptail Lizards than to Gila monsters.
   b. Snakes are more closely related to Monitor Lizards than to Wall lizards.
   c. All the reptiles in this evolutionary tree have venom.
   d. Snakes are not squamate reptiles.

3. According to evolutionary theory, venom has evolved in the ancestors of snakes over time. How much time do you think the evolution process might have taken?

   a. 200 hundred million years
   b. 2 million years
   c. 2,000 years
   d. 2 billion years

4. Many of the fossils that are being examined to identify ancestors in the evolutionary pathway of snakes have been found in marine limestone deposits in the Middle East, places that are now arid landscapes dotted with villages. The most scientifically reasonable explanation for the location of the fossils is:

   a. Ancient snakes lived in or along the shore of a sea, and were fossilized in this environment after death.
   b. Predators of snakes carried their prey into the sea to eat them.
   c. The great meteor impact caused a tidal wave that forced these animals into these areas trapping them and causing them to die, and their skeletons were fossilized
   d. The fossils are not ancient snakes, but the remains of reptiles that fell into the village wells.

5. The evolutionary history of snakes has been hotly debated. Recently, there has been a major shift in our understanding of the processes that have driven snake evolution. This indicates that:

   a. Gaps in the fossil record will never allow us to fully understand evolution.
   b. Aspects of evolution are constantly being challenged and explored in light of new evidence.
   c. Scientists studying evolution typically present ideas with very little evidence, leaving it to others to find proof of their ideas.
   d. Much of the science of evolution is based on speculation that can easily be changed when scientists think of new ideas.

6. The origins of the transformation from a surface-dwelling reptile to a burrowing reptile may be observed among some lizards that have lived in a grassland ecosystem for hundreds of years. These lizards like to eat burrowing rodents so much that they are often pushing their heads and bodies into soil to capture and eat them. If we returned millions of years later to observe these animals what might we see?

   a. Lizards that wanted to capture more rodents developed smaller limbs and more streamlined bodies.
   b. Two distinct but related lizards, one that lives on the ground surface and eats rodents caught above ground, the other lives underground and eats burrowing rodents.
   c. These lizards will become extinct because they will not be able to find other food and only their fossils will remain.
   d. There are so many possible outcomes that there is really no way to predict what will be seen.

Questions 7-12: Consider Figure 2 and the passage below to answer the questions that follow.

Both scales and feathers develop from disks of cells in the skin of bird embryos. Scaled skin is a characteristic of reptiles, and scales are found on the feet and legs of birds. The fossil record shows that birds evolved from non-avian dinosaurs, and that some non-avian dinosaurs had feathers. Scientists have identified two key genes in birds, BMP2 and Shh, that code for scales and for feathers. Changes in the developmental pathway lead to the formation of feathers with more complex structures. Scientists propose that the arrangement and actions of scale-making genes in non-avian dinosaurs was modified via evolution to form feathers.

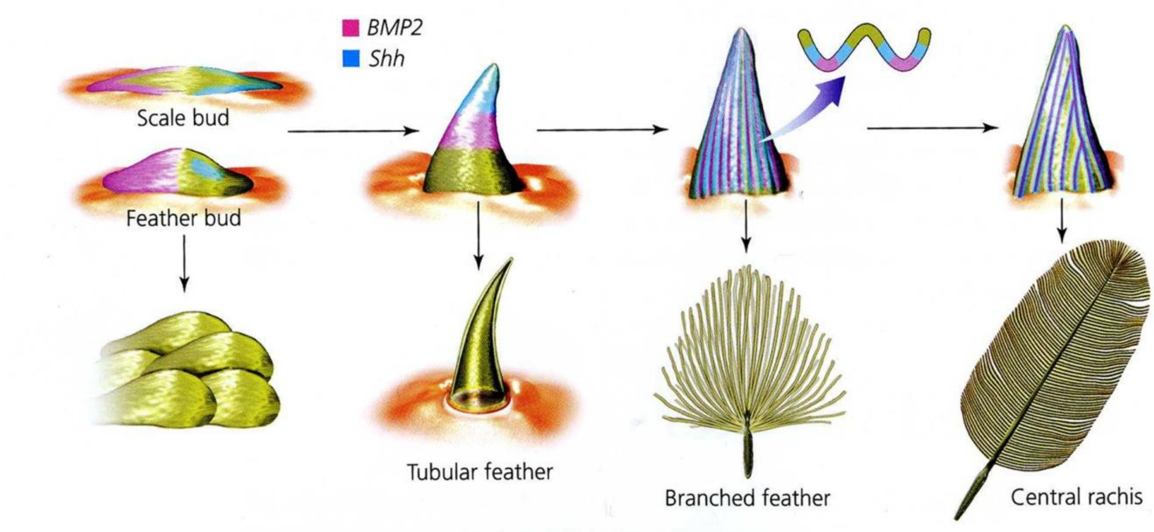


Figure 2: A hypothesis for the evolution of feathers. (Zimmer, 2010, p. 168)

7. In the evolution of bird feathers, it is apparent that some fundamental characteristics are retained. This supports the idea that:

   a. The organisms displaying these fundamental characteristics all have descended from an ancestor who most likely also had feathers.
   b. These are the only features that are effective for flight and therefore birds want to keep them so that they can fly.
   c. Feathers are essential for survival of birds so they struggle and work to retain these features.
   d. The genes that control the development of feathers in modern birds are different from those of ancient birds.

8. Some speculate that feathers are too complex to have resulted from evolution. Yet, evidence suggests some early non-avian dinosaurs may have had, in addition to scales, bristle-like feathers at least 160 million years ago. What might scientists infer about the feathers of the earliest non-avian dinosaurs?

   a. Only animals living in trees developed feathers because feathers helped them survive.
   b. Feathers would bear no resemblance to how feathers are structured today, and would not be recognized as feathers.
   c. The feathers of ancient birds would have some characteristics that are similar to feathers found in birds alive today.
   d. Only animals with scales would develop useful feathers.

9. Most preserved dinosaur fossils are bones and teeth, and it is difficult to find fossils of many types of feathers. This is because:

   a. Feathers sink down under the bodies and are buried by layers of fossilized bones.
   b. Feathers were so small that they are easily overlooked as fossils.
   c. Feathers were so different that scientists are not looking for the right structures.
   d. Feather structures typically decay before they can form fossils.

10. There is a variation in the size and condition of feathers within a population. This is an important consideration when trying to understand evolution because:

   a. Some individuals in a population are trying harder to grow better feathers than others.
   b. The variation in feather size and condition within a population can lead to the development of new feather structures.
   c. There are variations happening within all populations and they have no evolutionary significance.
   d. Variations indicate a species is no longer evolving but now stabilized.

11. Evidence for the development of feathers is based primarily on the observations of birds alive today. This means:

    a. Because present day birds have all developed many types of feathers, useful inferences about changes in the earliest feathers are very difficult to make.
    b. Scientists must assume that the feathers of birds today are the same as their extinct ancestors.
    c. Feathers are a recent development, evolutionarily speaking, and scientists cannot understand the structure of feathers in the past based on evidence of feathers today.
    d. The structure of the feathers in some birds today supports scientists' views of how feathers developed over time.

12. Different organisms are classified based on similar functions and forms. The feather types above in Figure 2 are found in modern birds and some non-avian dinosaurs. Yet, the genes that form the feather structures are not preserved as fossils, but have been identified in modern birds, which suggests that classification of modern birds as dinosaurs has been based on evidence that indicates:

    a. They can be traced back to a common ancestor that had feathers.
    b. That they all live in a similar location and needed feathers to fly.
    c. They want to be able to use flight to chase after prey and avoid predators.
    d. Feathers are not considered when grouping these organisms.

Questions 13-18: Consider the figure and passage below and answer the questions that follow.

Extinction is extremely important in the history of life. It can be a frequent or rare event within a lineage. Every lineage has some chance of becoming extinct. Over 99% of the species that have ever lived on Earth have gone extinct. This diagram illustrates the evolutionary history of several vertebrate species.

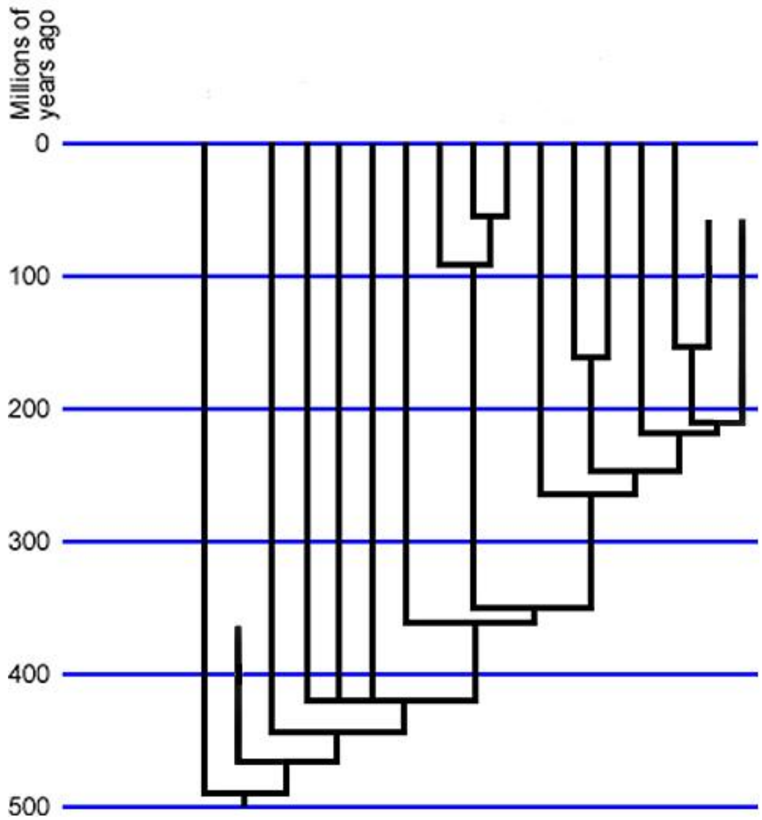


Figure 3: The historical development of the lineages of several vertebrate species. (adapted from Understanding Evolution, 2011a)

13. The diagram above indicates that all of the vertebrate animal species originated from the same:

    a. Kingdom.
    b. Location on the planet.
    c. Ancestor.
    d. Family.

14 If each of the vertical lines in the diagram above represents a lineage, what is being shown about the number of species present over time?

a. Constant, yet gradual, decrease in number of species.
b. Constantly diversified into an increased number of species.
c. Increases and decreases in the number of species present over time.
d. Mostly remained unchanged and stable and have experienced little change over time.

15. The branching of the vertebrate species as displayed above would happen:

a. Within a few generations.
b. Daily.
c. Over relatively long periods of time – millions of years.
d. Within an organism's life span.

16. The formation of branching diagrams like the one presented above is based on:

a. Genes and body structures.
b. Common names of the organisms.
c. Elevation and location in which the fossils were discovered.
d. Ecosystem in which modern organisms are now naturally found.

17. A few lineages in the diagram terminate prior to the top of the tree. This indicates that these species are now extinct. Our awareness of their existence is often based on fossils and this suggests that they:

a. Died in locations in which there was no food.
b. Were organisms with bones, exoskeletons, or left impressions.
c. Were thought to be primarily prey killed off by the surviving predators.
d. All had similar life cycles because they are all present in the fossil record.

18. The branching in the diagram above indicates the development of new species. When new species arise, generally:

a. New species immediately appear very different and that is why the branch is created.
b. New species have characteristics that are similar to the original species.
c. The original species will soon become extinct because the new species is better adapted to the environment.
d. The original species will no longer have the need or desire to evolve.

Questions 19-23: Consider the figure and passage below and answer the questions that follow.

The graphic below is a suggested evolutionary tree of the Primates. The arrangement of this tree is based on genetic information taken from the mitochondria of the various primates. (adapted from Lebedev, et al. 2000)

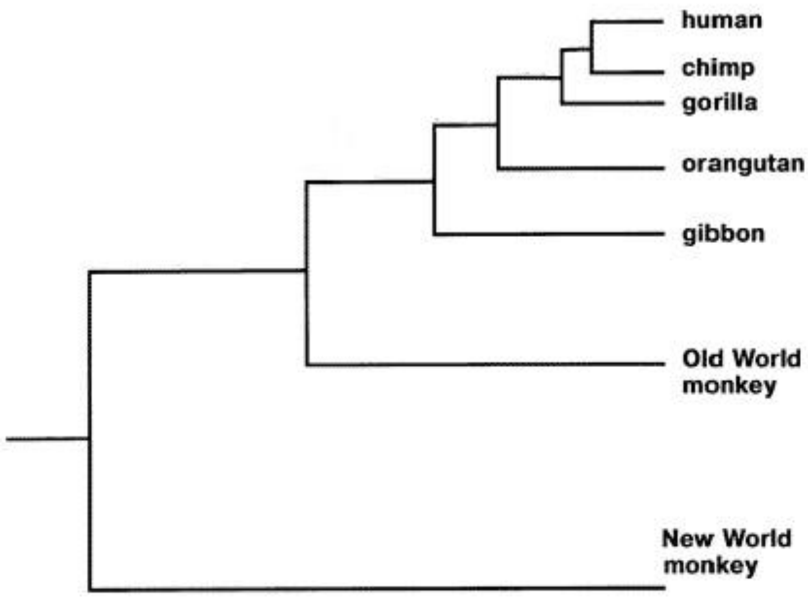


Figure 4: Hypothesized evolutionary history of the Primates.

19. The diagram above suggests that:

    a. Humans and Chimpanzees are the most closely related of all the Great Apes.
    b. New World Monkeys and Gibbons are more closely related than Old World Monkeys and Humans.
    c. Humans are much more complex than the other apes.
    d. New World monkeys are unrelated to Humans.

20. The diagram above suggests that:

    a. Gibbons include the most recently evolved species and New World Monkeys are the most ancient species of primates.
    b. Old World Monkeys, Gibbons, and Orangutans share a more recent common ancestor than do Humans and Chimpanzees.
    c. There has always been at least 5 species of Great Apes.
    d. Chimpanzees and Humans share a more recent common ancestor than do Old World Monkeys and New World monkeys.

21. All Great Apes are theorized to have evolved from a common ancestor. Given that this process took place over time, how much time do you think the process of evolution in this group of organisms might take?

a. Three million years.
b. Thirty million years.
c. Three billion years.
d. Thirty thousand years.

22. The fossil record for early humans is very sparse compared to many other organisms. In the context of the Primate tree this means:

a. The evolutionary relationships of humans are relatively easy to determine based on the wide variety of humans alive today.
b. Much of the evolutionary relationships of humans and the other primates is opinion and based on guess.
c. Analyses of genetic codes and anatomy are used to understand such relationships.
d. Humans have not undergone many evolutionary changes and remain at the top of the tree.

23. In advanced discussions of the evolution of the Great Apes, one will see a number of different evolutionary trees, each suggesting a different relationship between the different groups of Apes. These discrepancies suggest:

a. Scientists remain uncertain if any of the Great Apes are really related and are continuing to try to prove this.
b. Processes and small differences in methods can produce very different evidence that can be interpreted in different ways.
c. Anything aside from fossils is a weak form of evidence for the support of evolutionary theory.
d. Scientists remain uncertain why Humans would want to evolve and are continued to be seen as the superior species.

Question 24-27: ***Consider the figure and passage below and answer the questions that follow.*** The graphic below is a map depicting where mite harvestmen have been found on different continents. This map also depicts our best understanding of the relative position of some of the continents in Earth's early history.

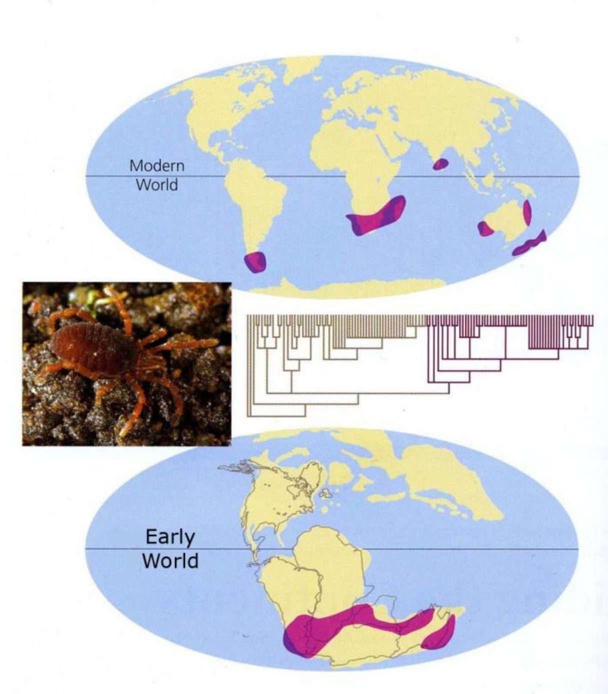


*Figure 5: The distribution of mite harvestmen across today's continents. The map shows how the continents may have once been positioned. (*adapted from Zimmer, 2010, p. 214*)*

One lineage of mite harvestmen can be found on continents and islands separated by thousands of miles of ocean. During Earth's early history, the ranges of these invertebrates formed a continuous belt. Later, the continents broke apart and moved away, taking the mite harvestmen with them.

24. The separation of the continents and the separation of the mite harvestmen on these continents allowed for:

   a. Mite harvestmen to interbreed, as their home ranges changed they joined together with other groups of mite harvestmen.
   b. Mite harvestmen to remain unchanged, given the very slow movement of the continents and the slow rate of evolution.
   c. Extinction, as the mite harvestmen were separated they could not survive as smaller groups.
   d. The production of new species, as groups of mite harvestmen were permanently separated.

25. If a similar fossil of mite harvestmen was found on different continents, scientists might infer that:

a. The continents involved were once connected.
b. Eventually, mite harvestmen will want to spread out and will be found on every continent.
c. The mite harvestmen were aware enough to know it was vital to move between continents.
d. They must have come from different species but all look the same.

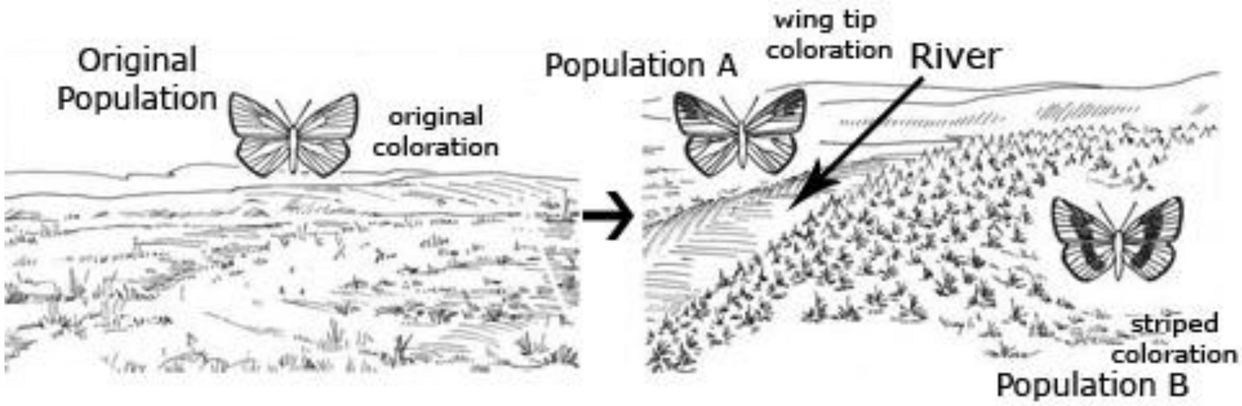
26. The theory of plate tectonics was largely discredited when it was first proposed. Fossil evidence gave additional support to this theory. The theory then began to be much more widely accepted by scientists. This demonstrates that:

a. Knowledge about historical events is particularly weak.
b. Theories are often supported by a number of different lines of evidence.
c. Scientific theories change very easily and are frequently just seen as hunches.
d. Nobody can ever really know how plate movement as described by plate tectonics takes place.

27. The Early World map depicted in the graphic shows the supercontinent of Pangea breaking up. Pangea began breaking up roughly:

a. Five million years ago.
b. Three hundred and fifty thousand years ago.
c. One and a half billion years ago.
d. One hundred fifty million years ago.

28. Explain in as much detail as possible how a single species of butterfly found in the graphic on the **left** could give rise to the two species of butterfly found in the graphic on the **right.**



APPENDIX C

Measure of the Acceptance of the Theory of Evolution
– Modified from Rutledge and Warden (1999)

Instructions: Indicate your level of agreement with the statements below by drawing a line (from left to right) and stopping your colored pencil at the appropriate position on the line to reflect your level of agreement. Put an “X” above the end of the line you drew.

1. Evolution is a scientifically valid theory.

Strongly Agree — Strongly Disagree

2. Evolutionary theory generates testable predictions with respect to the characteristics of life.

Strongly Agree — Strongly Disagree

3. The theory of evolution brings meaning to the diverse characteristics and behaviors observed in living forms.

Strongly Agree — Strongly Disagree

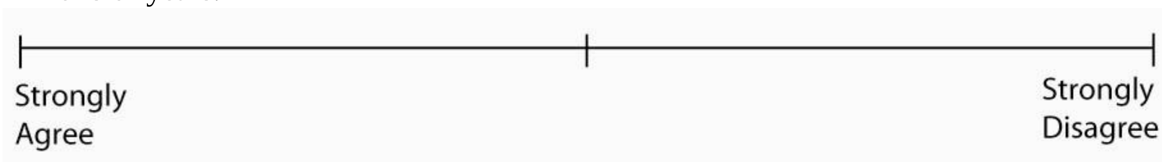
4. The available data are ambiguous as to whether evolution actually occurs.

Strongly Agree — Strongly Disagree

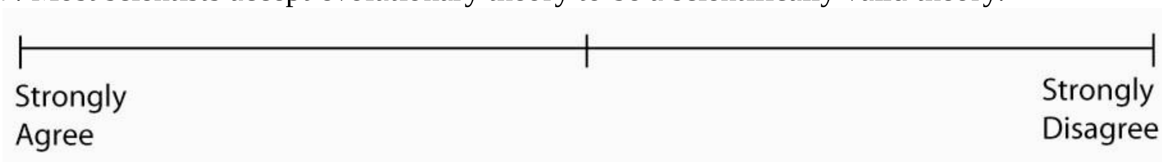
5. With few exceptions, organisms on earth came into existence at the same time.

Strongly Agree — Strongly Disagree

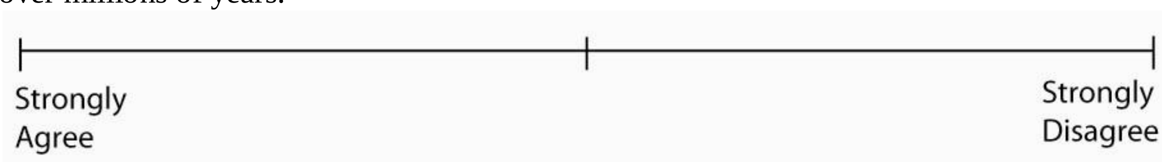
6. Modern humans are the product of evolutionary processes which have occurred over millions of years.



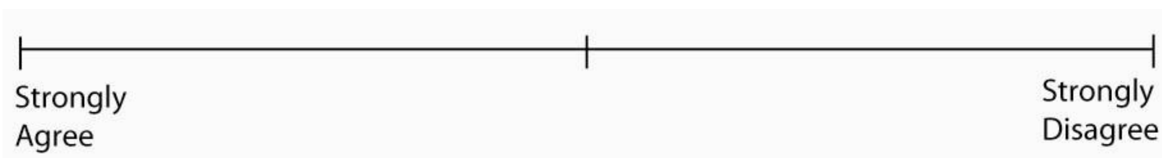
7. Most scientists accept evolutionary theory to be a scientifically valid theory.



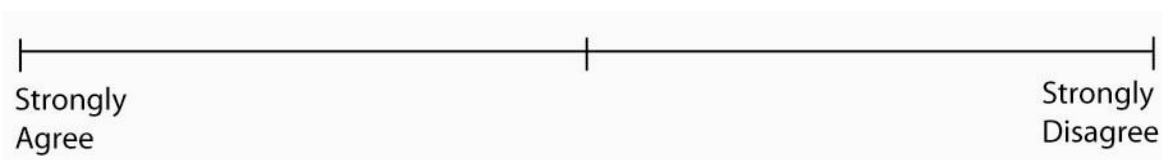
8. Organisms existing today are the result of evolutionary processes that have occurred over millions of years.



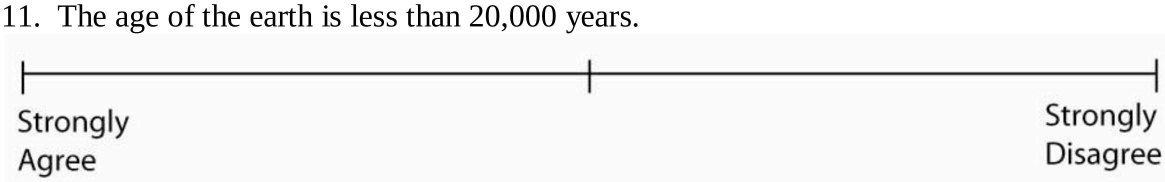
9. Current evolutionary theory is the result of sound scientific research and methodology.



10. Humans exist today in essentially the same form in which they always have.



11. The age of the earth is less than 20,000 years.



12. The theory of evolution is incapable of being scientifically tested.

Strongly Agree — Strongly Disagree

13. Organisms exist today in essentially the same form in which they always have.

Strongly Agree — Strongly Disagree

14. Evolutionary theory is supported by factual, historical, and laboratory data.

Strongly Agree — Strongly Disagree

15. The theory of evolution is based on speculation and not valid scientific observation and testing.

Strongly Agree — Strongly Disagree

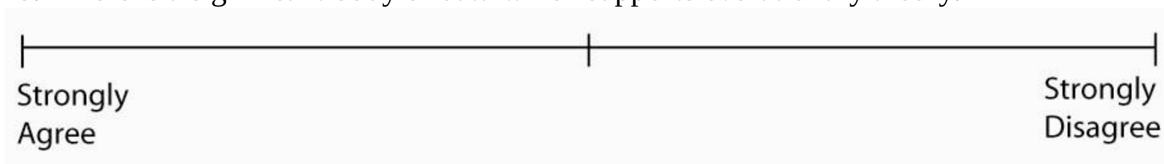
16. The age of the earth is at least 4 billion years old.

Strongly Agree — Strongly Disagree

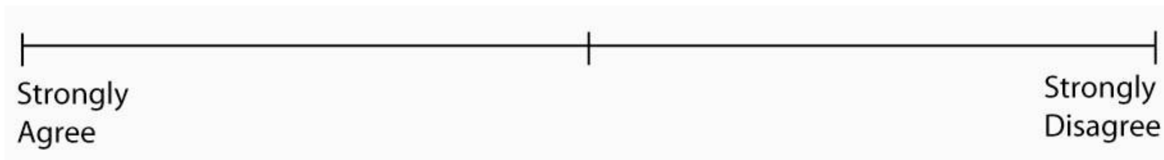
17. Much of the scientific community doubts if evolution occurs.

Strongly Agree — Strongly Disagree

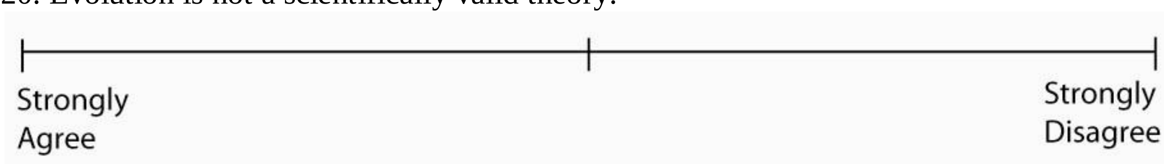
18. There is a significant body of data which supports evolutionary theory.



19. The theory of evolution cannot be correct since it disagrees with the Biblical account of creation.



20. Evolution is not a scientifically valid theory.



APPENDIX D

Workshop Reflection Questions

Introduction to Geology Reflection
2/12/2011

Please read each of these reflective prompts and answer them in the space provided as completely as possible.

1. What is a theory?
2. How would you respond to a student who said that a particular theory you are teaching about is "just a theory. It's just a guess and not a fact, not proven?
3. What were the most important things you learned today?
4. What from today will you take back and integrate into your classroom?
5. What questions do you still have about geology?
6. What questions do you have about geological time?

Geological Time Reflection
3/26/2011

Please read each of these reflective prompts and answer them in the space provided as completely as possible.

1. Why is understanding what a theory is important to understanding life through time?
2. What were the most important things you learned today?
3. What from today will you take back and integrate into your classroom?
4. What questions do you still have about geologic time?

Fossils and Fossilization Reflection
6/13/2011

Please read each of these reflective prompts and answer them in the space provided as completely as possible.

1. It is commonly accepted that the fossil record is incomplete. How do paleontologists explain this?

2. While visiting a museum with your students, one student notices an age of a fossil on display as 40 million years old. The student asks you how scientists know how old the fossil is. How would you explain to them how scientists date fossils?
3. How could you incorporate the activities we did together into your classroom? What changes would you make to make the lesson appropriate for you students?

<u>Exploring Biodiversity in the Field Reflection</u>
6/15/2011

Please read each of these reflective prompts and answer them in the space provided as completely as possible.

1. From all of the activities we did today, what can you take back to your classroom and use with your students? Describe any modifications that you would make to the activities for your students.
2. How can you translate your field experience into one that you can use in your own classroom?
3. Describe an activity that you could do with your students that incorporates the skills involved with the dichotomous key.

<u>Organisms and Their Environment Reflection</u>
6/16/2011

Please read each of these reflective prompts and answer them in the space provided as completely as possible.

1. How could you use the CT's Digimorph Website (www.digimorph.org) in your classroom?
2. One of your students was standing in line at the supermarket and saw a tabloid article on children who have a condition causing excessive facial hair growth. Some students are concerned that humans are evolving to have more facial hair. How would you help them understand that evolution happens at the population level, not at the individual level?
3. How do scientists hypothesize the function of unusual structures found in the fossil record?

Tree of Life Reflection
11/5/2011

In the space provided, reflect upon what you think was most significant about each activity, how you could incorporate the activity into your classroom, and what additional questions you have about the activity.

1. It’s All Relative (Card sort, Reading Trees, Sarahsaurus)
2. Trilobite and Primate Phylogeny
3. Human and Chimps: All In The Family

Plate Tectonics and Speciation Reflection
12/10/11

In the space provided, reflect upon what you think was most significant about each activity, how you could incorporate the activity into your classroom, what additional questions you have about the activity, or any other pertinent information about the activity.

1. Plate Tectonic Activity with Dr. Cloos
2. Plate Tectonic Activity: Field Work in Nepal
3. Speciation Overview
4. Clipbirds Activity

APPENDIX E

Pretraining and Posttraining Interview Protocol

<u>Pretraining Interview Questions</u>

Say: Thank you for agreeing to be interviewed. In this interview I'm interested in hearing about teaching and learning about evolution in your classroom.

Teaching evolution:

- What evolution-related concepts do you teach?
- What do you need to know to be able to teach evolution?
- How do you decide what evolutionary concepts you are going to teach?
    - *Follow-up probe if not addressed in original response –Does anyone impact your decision about what will be taught? If so, whom and how?*
- What more do you need to know to be able to teach evolution more effectively?

Say: For this portion of the interview I'll pose a scenario and ask you how you think you would respond. These scenarios don't have right or wrong answers.

Challenges to teaching evolution:

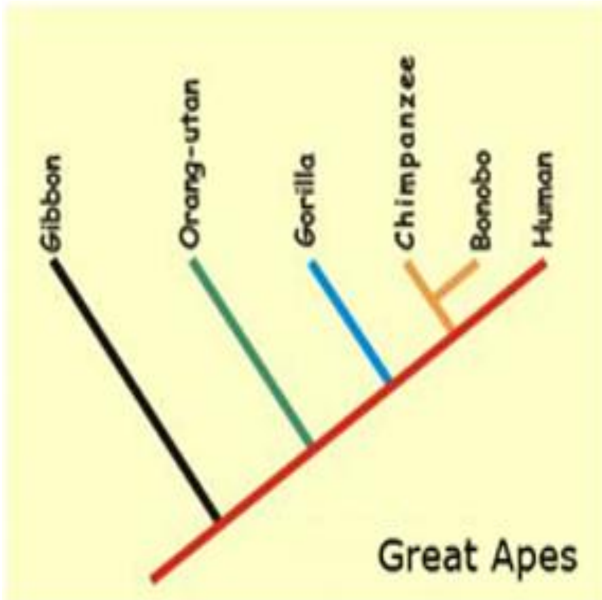
- What do you find to be most challenging when teaching about evolution?
- How would you respond to a parent who tells you she doesn't believe in evolution and asks you how it will be taught in your class?
- After teaching a lesson about fossils providing evidence of past life and evidence for evolution, a student asks you if you believe in evolution. How do you respond?

Macroevolution PCK:

Nature of science: How would you respond to a student who said that evolutionary theory is "just a theory"?

Fossils: You take your students hiking on a tall mountain. One of your students picks up a shell fossil on top of the mountain. The shell fossil is of an organism that lived in the ocean. The student asks you how the fossil got to the top of the mountain. How do you respond?

Phylogenetics: One of your students was reading the newspaper and saw this cladogram (*show cladogram)*. She brings the cladogram to you and asks you to explain what it is showing. What do you tell her?



- *Follow up probes if not mentioned by interviewee: Why are humans on the far right of the cladogram? Why are the chimpanzee and bonobo off the same branch?*

Speciation: The Galápagos Islands are a string of volcanic islands about 600 miles off the coast of South America. When the islands first emerged from the sea floor, they were lifeless piles of lava rocks. A few million years ago, one species of finch migrated to the Galápagos Islands from the mainland of Central or South America. From this one migrant species at least 13 species of finch evolved. Describe a lesson in which you could help your students understand how the different species of finch could have evolved from a single ancestor.

Deep time: You are going to teach your students about deep time. What are the challenges associated with learning this concept? How will you teach it?

- *If participant isn't clear on what deep time means, explain deep time is the concept that the geologic time scale is vast because the Earth is very old.*

Posttraining Interview Questions

Say: Thank you for agreeing to be interviewed. In this interview I'm interested in hearing about teaching and learning about evolution in your classroom.

Teaching evolution:

- What evolution-related concepts do you teach?
- What do you need to know to be able to teach evolution?

Effect of professional development

- How did you/will you (*depending on time of year taught)* introduce evolution-related concepts to your students this year?
- What from the *Life Through Time* professional development series did you incorporate into your teaching?
- What aspect(s) of the professional development series most impacted your teaching?
- How prepared do you feel to teach evolution?
- What more do you need to effectively teach evolution?

Say: For this portion of the interview I'll pose a scenario and ask you how you think you would respond. These scenarios don't have right or wrong answers.

Challenges to teaching evolution:

- What do you find to be the most challenging aspects of teaching evolution?
- How would you respond to a student who says he doesn't believe in evolution and asks you how it will be taught in your class?
- How would you respond to a student who asks if you believe in evolution?

Macroevolution PCK:

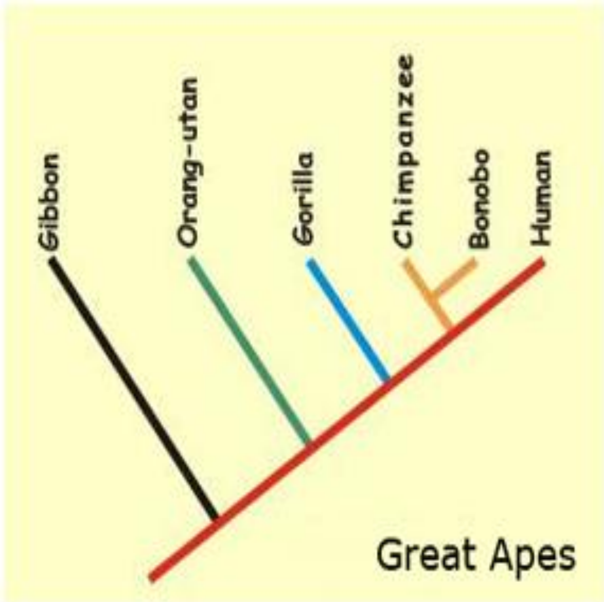
Nature of science: *Read teacher probe to the participant*:
Four students were having a discussion about how scientists do their work. This is what they said:

> Antoine: I think scientists just try out different things until something works."
> Tamara: "I think there is a definite set of steps all scientists follow called the scientific method."
> Marcos: "I think scientists use different methods depending on their question."
> Avery: "I think scientists use different methods but they all involve doing different experiments."

Which student do you most agree with? Explain why you agree with that student and why you disagree with the other students.

Fossils: You're teaching your students about different lines of evidence for evolution. One student says, "The fossil record provides evidence for evolution." Another student disagrees, "There are gaps in the fossil record, so the fossil record doesn't provide evidence for evolution?" How would you respond?

Phylogenetics: You are teaching your students about the evolutionary relationships of the Great Apes using this cladogram (*show cladogram).* When you show the cladogram to the class, a student says, "I didn't evolve from a monkey." How would you respond?



Speciation: You are going to teach your students how speciation by geographic isolation occurs. Describe a lesson in which you teach this concept.

- *If participant isn't clear on what speciation means, explain speciation is a lineage-splitting event that produces two or more separate species. If participant isn't clear on what geographic isolation means, explain it is when a part of a population of the same species become separated by a physical barrier.*

Deep Time: Your students understand that deep time involves events that occurred far in the past and tend to group events into two groups: the ancient past and less ancient past. However, they don't know details of the sequence of events that occurred during these time periods. Describe a lesson in which you could help student develop an understanding of the sequence of events occurring throughout deep time.

- *If participant isn't clear on what deep time means, explain deep time is the concept that the geologic time scale is vast because the Earth is very old.*

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Vita

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